Naval Biodynamics Laboratory
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ANTHROPOMETRY AND MASS DISTRIBUTION FOR HUMAN ANALOGUES

VOLUME I: MILITARY MALE AVIATORS

March 1988

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Anthropometry and Mass Distribution for Human Analogues

Volume I: Military Male Aviators

March 1988

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Anthropometric and mass distribution data for use in constructing three-dimensional human analogues -- mathematical models or test dummies -- are presented in this report. Included here are body dimensions, joint locations, and mass distribution properties appropriate for modeling the Small, Mid-size, and Large male aviator of the 1980s. The data were derived from: (1) 139 body dimensions of standing and seated males obtained by traditional anthropometric methods; (2) mass distribution data for body segments obtained by stereophotographic techniques; and (3) skeletal joint centers obtained by estimation. The anthropometric data, generated from multiple regressions on stature and weight, are suitable as the basis for models to be used in testing responses to impact and other mechanical forces; they are not recommended for other purposes such as the sizing of clothing and personal protective equipment, or workspace design.

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PREFACE

This publication is the culmination of a project initiated more than seven years ago by Mr. Joe Haley of the U.S. Army Aeromedical Research Laboratory (USAARL). A great many people, including representatives from industry, academic institutions, and a number of government agencies, cooperated in the development of this tri-service data base for use in the construction of three-dimensional human analogues. The lengthy process of generating and selecting data appropriate and acceptable to the Air Force, Army, and Navy was begun on 13 March 1980 at the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL). Final coordination and agreement was achieved through the Tri-Service Working Group on Biomechanics, which facilitated the achievement of specifications acceptable to all three services, and provided for final report preparation.

Special acknowledgement is made to Mr. Richard Chandler and Mr. Joe Young of the Civil Aeromedical Institute of the Federal Aviation Administration for their recommendations, to Dr. Ints Kaleps of the AAMRL for coordinating and incorporating comments and recommendations, and to the staff of Anthropology Research Project, Inc. for conducting numerous analyses and preparing the final report. Illustrations were designed and executed by Gary Ball.

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INTRODUCTION

The comparative testing, analysis and evaluation of the safety and performance of manned systems require the use of standardized mechanical or analytical human surrogates which approximate human body properties. This document provides the design parameters for the Small, the Mid, and the Large sized male aviator, with mass distribution and body size appropriate for the 1980-1990 time period. Included in this document are data for body dimensions, joint locations, and mass distribution properties.

The data provided in this document are meant to serve as a basis for three-dimensional mathematical models and test dummies which are to be used for investigating responses to impact or other mechanical forces. The dimensions in this report have been generated from multiple regressions on stature and overall body weight. This method provides internally consistent body dimensions for each model but does not necessarily provide appropriate descriptive statistics for a population for any single dimension. For example, when compared to the 1967 survey of U.S. Air Force rated male aircrew (Churchill, Kikta and Churchill, 1977), the Small and Large values for head breadth in this document rank at 38th and 69th percentiles, respectively. Only 31% of the Air Force survey personnel fall within these bounds. Therefore, it is strongly recommended that the data in this document not be used for purposes such as fit analysis, sizing of personal protective equipment and clothing, or for workspace design or evaluation.

ANTHROPOMETRY

Data Base

The criteria in this document are derived from: (1) body dimensions obtained by traditional anthropometric methods; (2) mass distribution data obtained by stereophotographic techniques; and (3) skeletal joint centers obtained by estimation. All computations for the Small, Mid-size, and Large male aviator are based on stature and weight.

Body Size

A total of 139 body dimensions of standing and seated males are reported here. Most of these anthropometric measurements were derived from stature and weight multiple regression equations calculated from the 1967 survey of U.S. Air Force rated male aircrew. The stature and weight values used were the 3rd, 50th, and 95th percentiles projected to reflect assumed increases in body size between 1967 and the 1980-1990 time period (Churchill and McConville, 1976). Those dimensions not measured in the 1967 survey were derived from those data or were estimated from other studies (McConville and Laubach, 1978; McConville et al., 1980) and are marked with an asterisk. Body dimensions are referenced to the standard "anatomical position," with the head in the Frankfort plane, unless otherwise specified in the measurement description. This position and body reference terminology is illustrated in Figure 1. For design purposes, the body is assumed to be bilaterally symmetrical. Dimension descriptions and measurement data are given in Table 1.

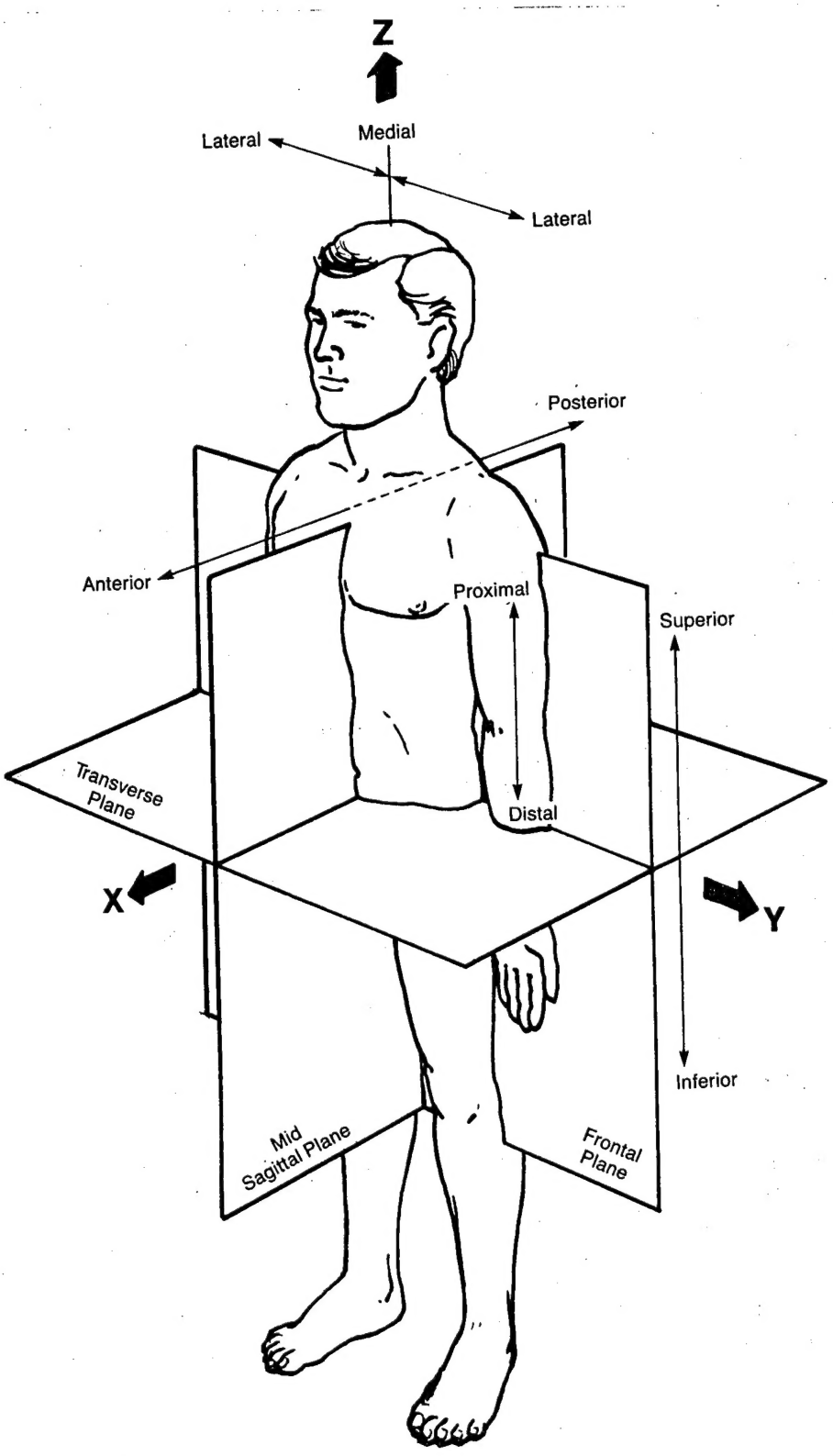


Figure 1. The body in standard anatomical position.

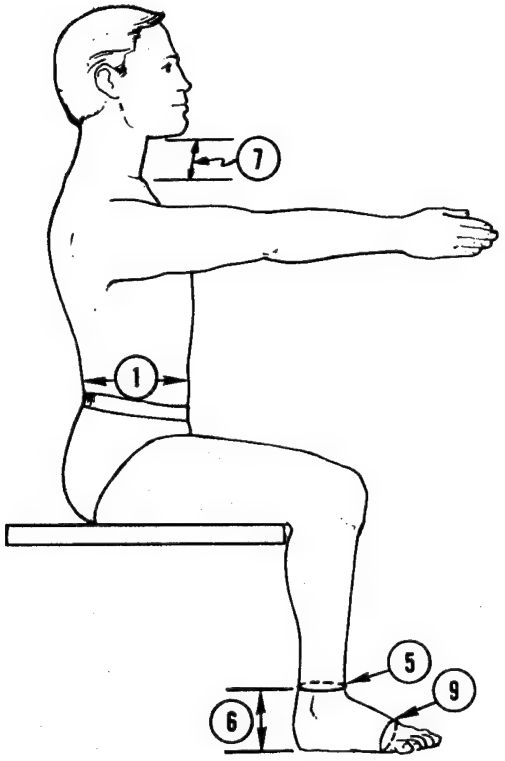
TABLE 1

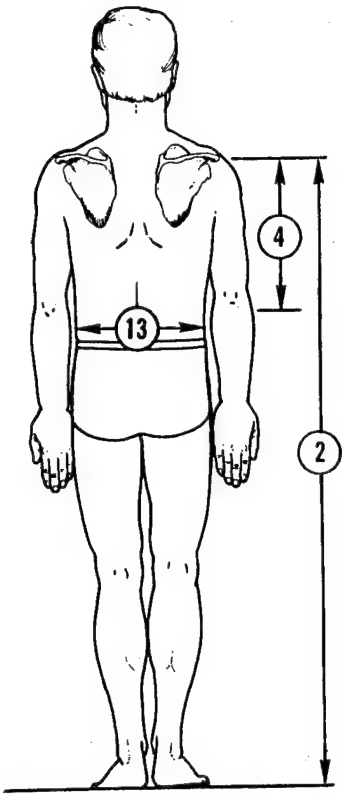
DIMENSIONS OF THE SMALL, MID-SIZE AND LARGE MALE AVIATOR

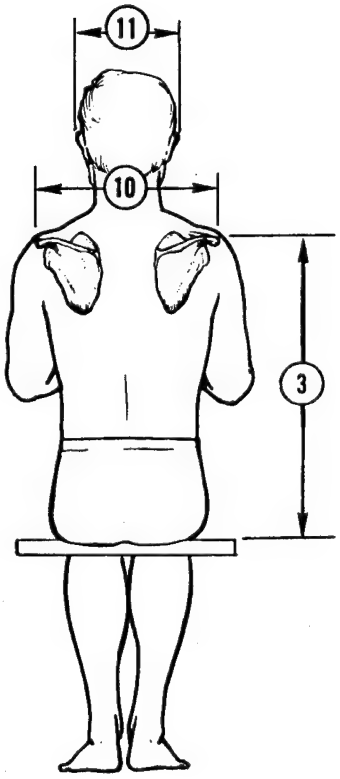
Dimension Descriptions	DESIGN VALUES (cm)		
	SMALL	MID	LARGE
*1 ABDOMINAL DEPTH, SITTING: The maximum horizontal depth of the abdomen.	22.4	25.5	28.1
2 ACROMIAL HEIGHT: The vertical distance between the standing surface and the lateral tip of the shoulder (acromion).	136.6	146.2	155.7
3 ACROMIAL HEIGHT, SITTING: The vertical distance between the sitting surface and the lateral tip of the shoulder (acromion).	57.8	61.5	65.0
4 ACROMION-RADIALE LENGTH: The length of the upper arm measured as the vertical distance between the lateral tip of the shoulder (acromion) and the proximal end of the radius (radiale).	31.1	33.2	35.2
5 ANKLE CIRCUMFERENCE: The minimum horizontal circumference of the lower leg (calf).	21.1	22.7	24.1
6 ANKLE HEIGHT: The vertical distance between the standing surface and the level of the ankle circumference.	13.0	13.8	14.6
7 ANTERIOR NECK LENGTH: The surface distance in the midsagittal plane between the point of the deepest depression of the top of the breastbone (suprasternale) and the juncture of the neck and the jaw.	8.3	8.4	8.5
*8 AXILLA HEIGHT: The vertical distance between the standing surface and the apex of the armpit (axilla).	126.6	135.1	143.6
9 BALL OF FOOT CIRCUMFERENCE: The circumference of the foot passing over the maximum protuberance of the first metatarsal bone and the fifth metatarsal bone.	23.6	25.0	26.4
10 BIACROMIAL BREADTH: The horizontal distance between the lateral tips of the shoulders (right and left acromion).	39.1	41.0	42.8
11 BIAURICULAR BREADTH: The horizontal distance between the most lateral points of the right and left ears.	18.4	18.9	19.3
12 BICEPS CIRCUMFERENCE: The circumference of the upper arm perpendicular to its long axis, measured with the arm hanging relaxed at the side. (The level of the dimension is established at the maximum protrusion of the flexed biceps.)	28.4	31.3	33.7
13 BICRISTAL BREADTH (Bone): The maximum horizontal distance between the lateral crests of the pelvis (ilia) measured with enough pressure to compress the tissue.	25.8	28.3	30.5

* See section on Body Size, page 6.

TABLE 1 (cont'd)







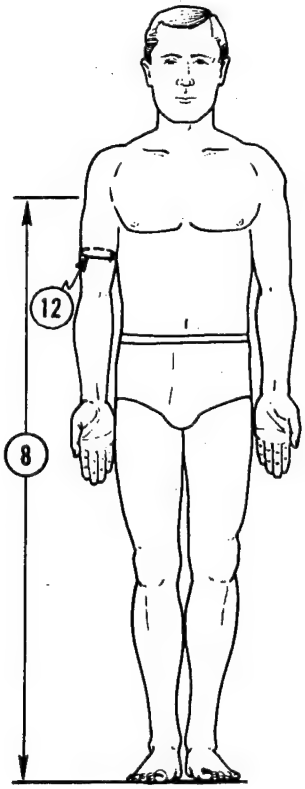


TABLE 1 (cont'd)

Dimension Descriptions	DESIGN VALUES (cm)		
	SMALL	MID	LARGE
14 BIDELTOID BREADTH: The maximum horizontal distance across the shoulders at the level of the deltoid muscles.	45.3	48.8	51.9
15 BIGONIAL BREADTH: The horizontal distance between the corners of the jaw (right and left gonion).	11.4	11.8	12.2
16 BIMALLEOLAR BREADTH: The maximum horizontal distance between the lateral and the medial protrusions of the ankle (medial and lateral malleolus).	7.0	7.4	7.8
17 BIOCULAR BREADTH: The horizontal distance between the outer corners of the eyes (right and left ectocanthus).	9.0	9.2	9.4
18 BITRAGION BREADTH: The horizontal distance between the right and the left tragion (the point at the top of the cartilaginous flap in front of the opening of the ear).	13.9	14.3	14.7
19 BITRAGION-CORONAL ARC: The vertical surface distance between the right and the left tragion passing over the top of the head.	35.0	35.9	36.7
20 BITRAGION-MENTON ARC: The surface distance between the right and the left tragion passing over the tip of the chin (menton).	31.5	32.8	34.0
21 BITRAGION-MINIMUM FRONTAL ARC: The surface distance between the right and the left tragion passing over the greatest indentation of each temporal crest (frontotemporale).	30.2	30.9	31.6
22 BITRAGION-POSTERIOR ARC: The surface distance between the right and the left tragion passing over a bony midline point on the back of the head (inion).	28.7	29.6	30.4
23 BITRAGION-SUBMANDIBULAR ARC: The surface distance between the right and the left tragion passing over the juncture of the jaw with the neck.	29.6	31.2	32.6
24 BITRAGION-SUBNASALE ARC: The surface distance between the right and the left tragion, passing over the juncture of the nose with the philtrum.	28.6	29.4	30.2
25 BIZYGOMATIC BREADTH (Face Breadth): The horizontal distance between the maximum protrusions of the cheekbones (zygomatic arches).	13.9	14.3	14.7
26 BUTTOCK CIRCUMFERENCE: The horizontal circumference of the body at the level of the maximum protrusion of the buttocks.	91.1	100.0	107.8

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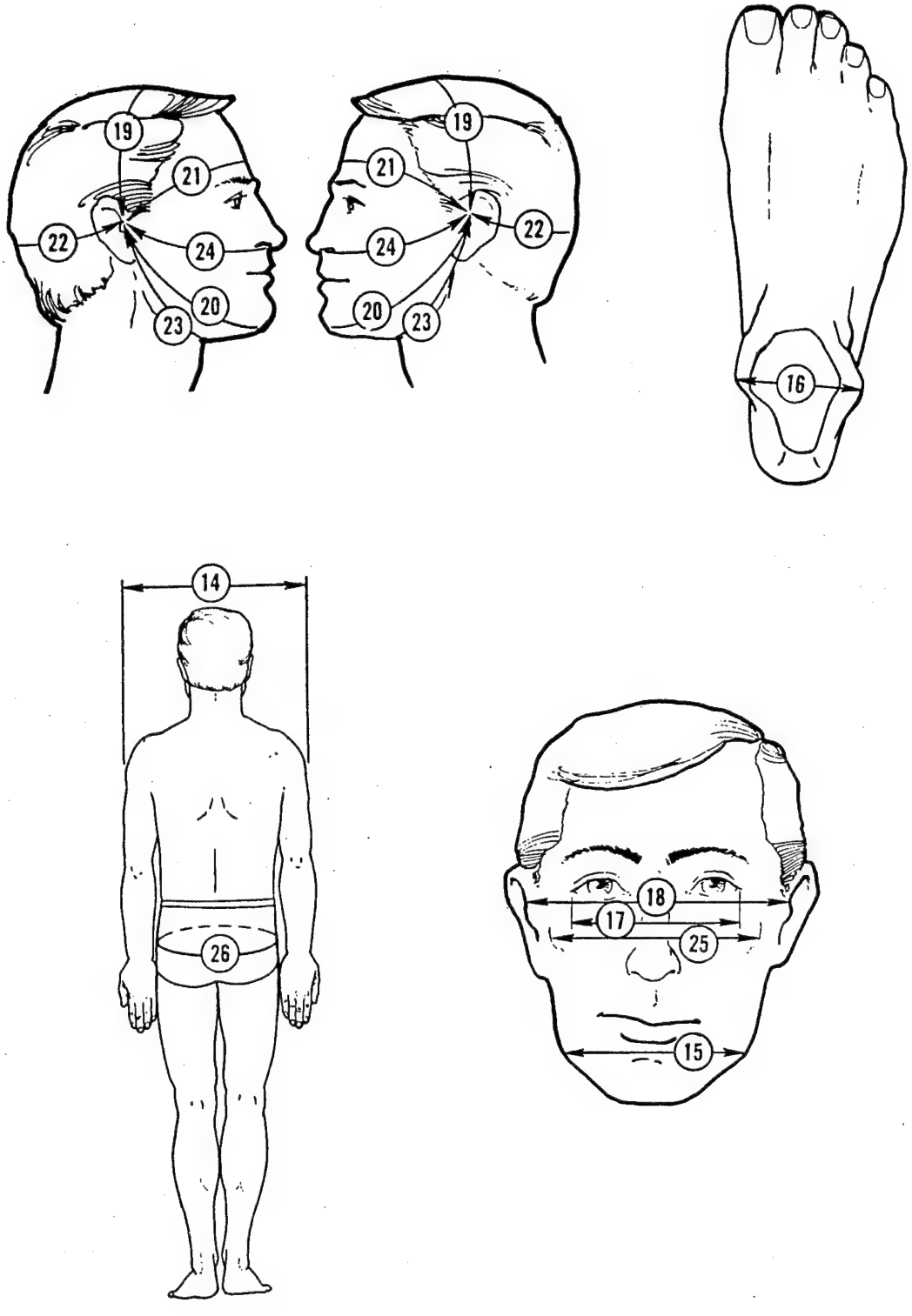
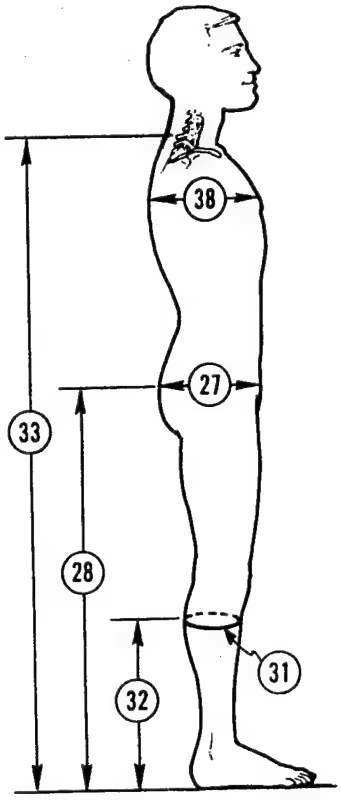


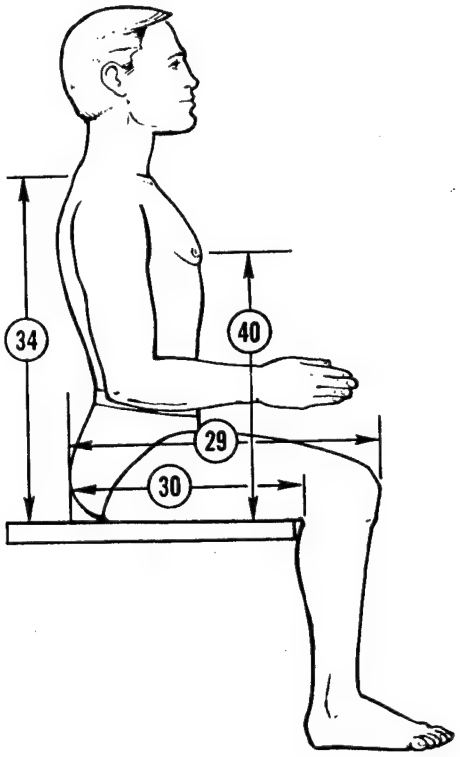
TABLE 1 (cont'd)

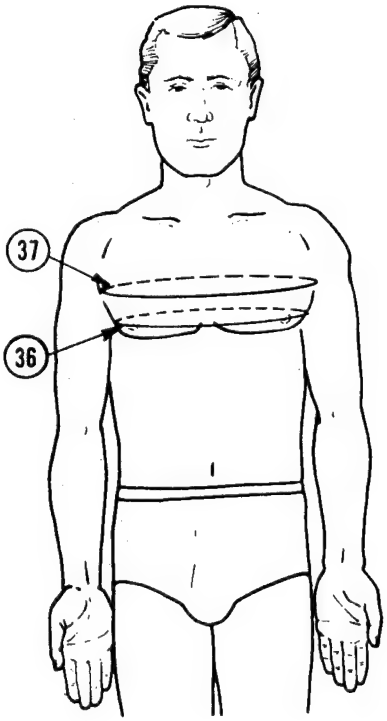
Dimension Descriptions	DESIGN VALUES (cm)		
	SMALL	MID	LARGE
27 BUTTOCK DEPTH: The horizontal depth of the body at the level of the maximum protrusion of the buttocks.	21.7	24.4	26.8
28 BUTTOCK HEIGHT: The vertical distance between the standing surface and the level of the maximum protrusion of a buttock.	84.4	90.8	97.0
29 BUTTOCK-KNEE LENGTH: The horizontal distance between the maximum protrusion of a buttock and the anterior point of the knee of a seated subject. The knee is flexed 90 degrees.	56.6	60.9	65.0
30 BUTTOCK-POPLITEAL LENGTH: The horizontal distance between the maximum protrusion of a buttock and the posterior surface of the knee of a seated subject. The knee is flexed 90 degrees.	47.1	50.8	54.4
31 CALF CIRCUMFERENCE: The maximum horizontal circumference of the calf.	34.7	37.7	40.3
32 CALF HEIGHT: The vertical distance between the standing surface and the level of the maximum circumference of the calf.	33.0	35.8	38.6
33 CERVICALE HEIGHT: The vertical distance between the standing surface and the tip of the spinous process of the 7th cervical vertebra (cervicale).	143.4	153.1	162.6
*34 CERVICALE HEIGHT, SITTING: The vertical distance between the sitting surface and cervicale.	64.6	68.4	72.0
35 CHEST BREADTH: The horizontal breadth of the chest at the level of the nipples.	30.5	33.2	35.6
36 CHEST CIRCUMFERENCE: The horizontal circumference of the chest at the level of the nipples.	91.2	100.0	107.5
37 CHEST CIRCUMFERENCE AT SCYE: The circumference of the chest at the level of an axillary fold (scye point).	95.3	103.6	110.8
38 CHEST DEPTH: The horizontal depth of the chest at the level of the nipples.	22.5	24.9	27.0
39 CHEST HEIGHT: The vertical distance between the standing surface and the level of the nipple.	121.9	130.1	138.2
*40 CHEST HEIGHT, SITTING: The vertical distance between the sitting surface and the level of the nipple.	43.1	45.4	47.6
41 CROTCH HEIGHT: The vertical distance between the standing surface and the midpoint of the crotch.	80.2	85.6	91.1

* See section on Body Size, page 6.

TABLE 1 (cont'd)







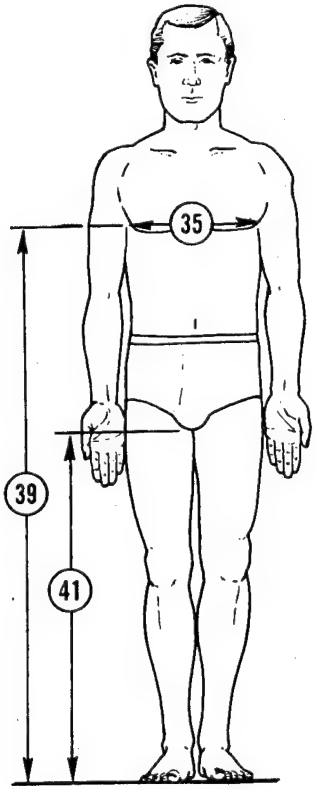
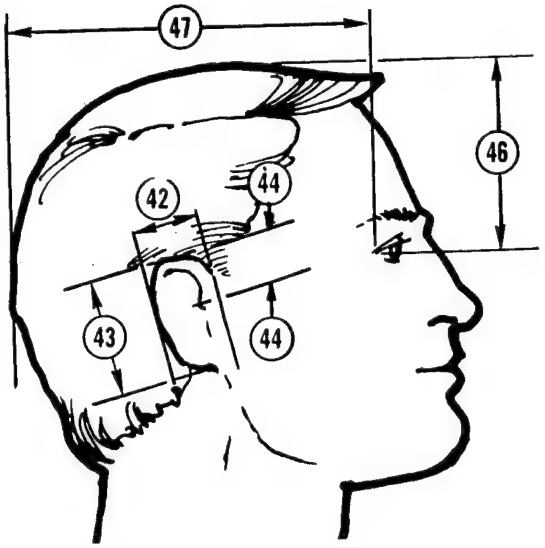
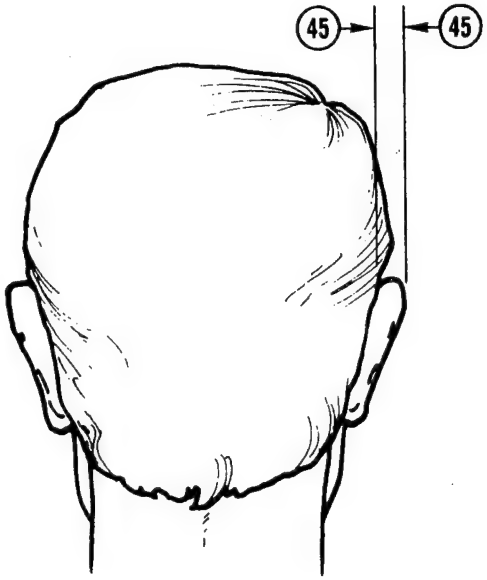


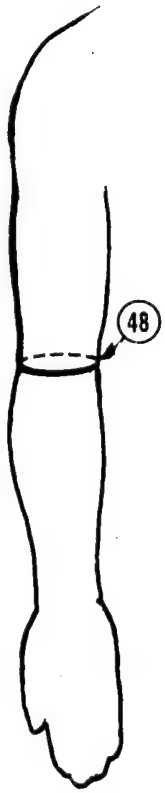
TABLE 1 (cont'd)

Dimension Descriptions	DESIGN VALUES (cm)		
	SMALL	MID	LARGE
42 EAR BREADTH: The breadth of the ear perpendicular to its long axis.	3.7	3.8	3.9
43 EAR LENGTH: The length of the ear along its long axis.	6.4	6.6	6.9
44 EAR LENGTH ABOVE TRAGION: The distance along the long axis from tragion to the top of the ear.	2.9	2.9	3.0
45 EAR PROTRUSION: The horizontal distance between the most protruding point on the surface of the ear and the bony eminence of the mastoid process immediately behind the ear.	2.1	2.2	2.3
46 ECTOCANTHUS TO TOP OF HEAD: The vertical distance between the outer corner of an eye (ectocanthus) and the plane of the top of the head.	11.7	12.0	12.2
47 ECTOCANTHUS TO WALL: The horizontal distance between the outer corner of an eye (ectocanthus) and the plane of the back of the head	17.5	17.8	18.1
48 ELBOW CIRCUMFERENCE: The circumference of the elbow perpendicular to the long axis of the arm passing over the tip of the elbow (olecranon process).	26.0	28.0	29.8
49 ELBOW HEIGHT: The vertical distance between the standing surface and the proximal end of the radius (radiale).	105.6	113.1	120.5

TABLE 1 (cont'd)







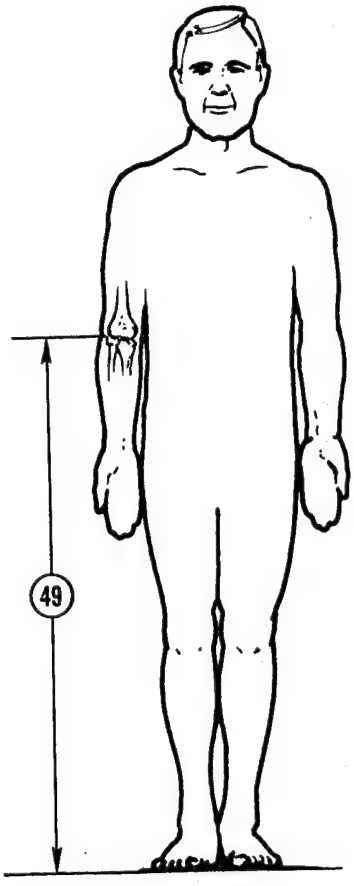
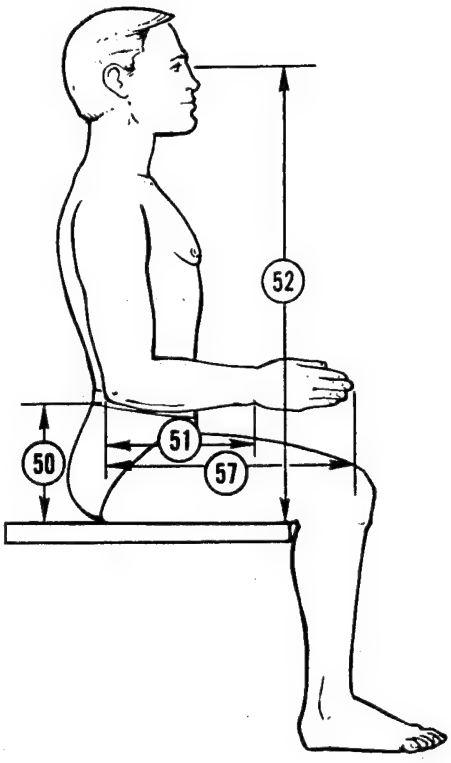


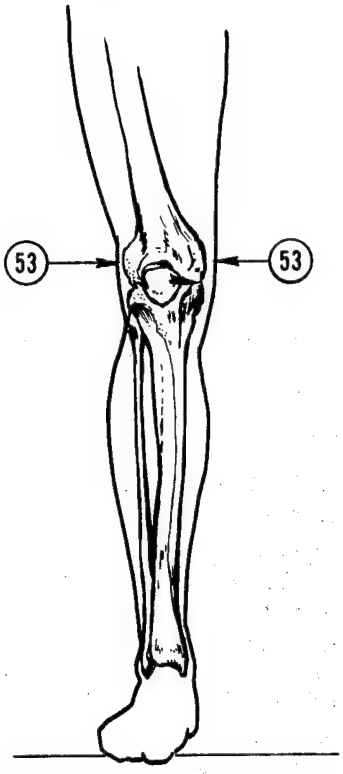
TABLE 1 (cont'd)

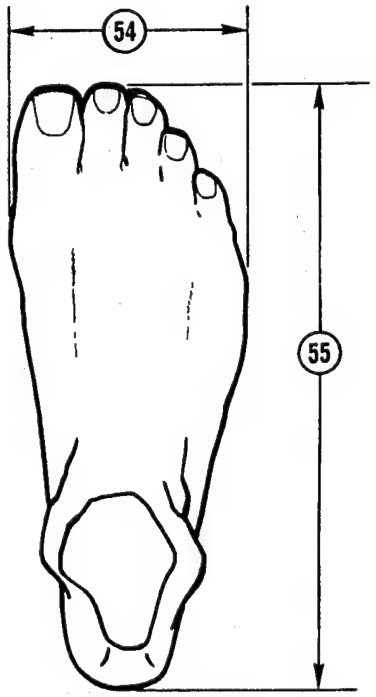
	Dimension Descriptions	DESIGN VALUES (cm)		
		SMALL	MID	LARGE
50	ELBOW REST HEIGHT: The vertical distance between the sitting surface and the bottom of the elbow with the upper arm hanging freely and the forearm flexed 90 degrees.	23.9	25.4	26.7
51	ELBOW-WRIST LENGTH: The distance between the tip of the elbow (olecranon process) and the distal end of the radius (stylion) with the upper arm hanging freely and the elbow flexed 90 degrees.	28.4	30.2	32.0
52	EYE HEIGHT, SITTING: The vertical distance between the sitting surface and the outer corner of an eye (ectocanthus).	77.5	81.4	85.1
53	FEMORAL BREADTH (Bone): The breadth of the femur between its medial and lateral epicondyles with the tissue compressed.	9.5	10.1	10.6
54	FOOT BREADTH: The maximum breadth of the foot perpendicular to its long axis.	9.3	9.8	10.3
55	FOOT LENGTH: The maximum length of the foot parallel to its long axis.	25.7	27.2	28.7
56	FOREARM CIRCUMFERENCE: The maximum circumference of the forearm perpendicular to its long axis.	26.5	28.5	30.2
*57	FOREARM-HAND LENGTH: The distance between the tip of the elbow (olecranon process) and the tip of the middle finger (dactylion) when the upper arm is hanging freely and the elbow is flexed 90 degrees.	46.6	49.3	52.0
58	GLABELLA TO TOP OF HEAD: The vertical distance from the midsagittal point between the browridges (glabella) to the plane of the top of the head.	9.2	9.3	9.4

* See section on Body Size, page 6.

TABLE 1 (cont'd)







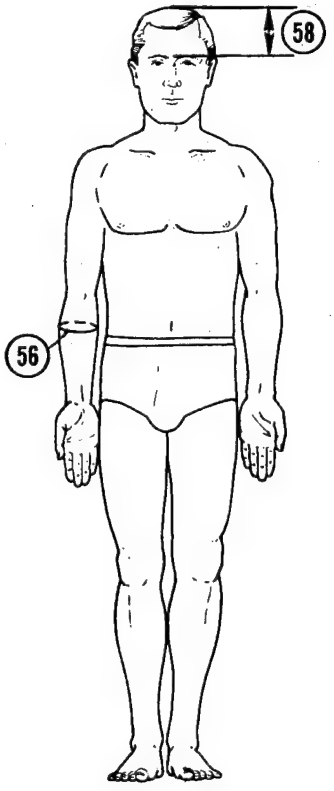
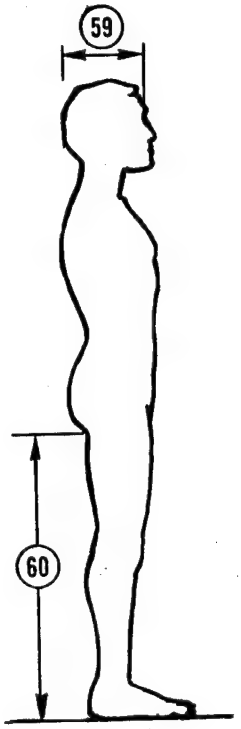
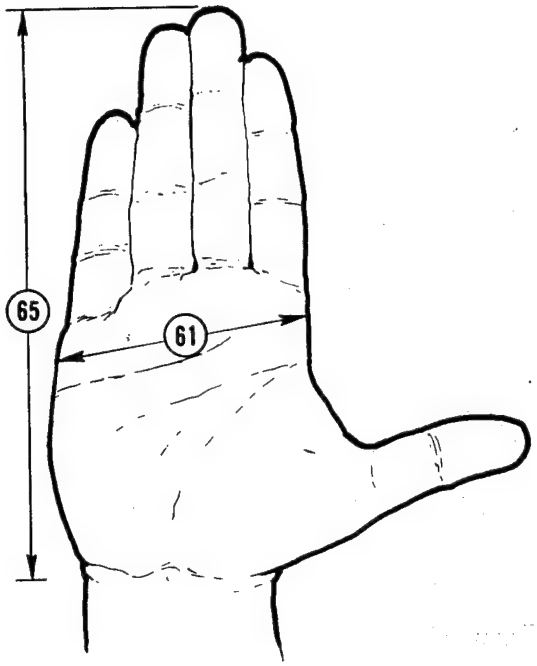


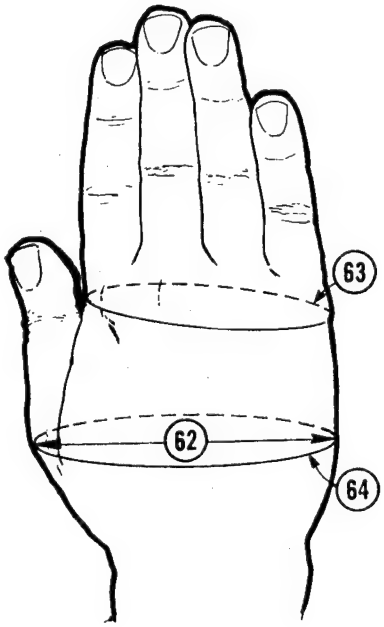
TABLE 1 (cont'd)

Dimension Descriptions	DESIGN VALUES (cm)		
	SMALL	MID	LARGE
59 GLABELLA TO WALL: The horizontal distance from the midsagittal point between the browridges (glabella) to the plane of the back of the head.	20.0	20.4	20.8
60 GLUTEAL FURROW HEIGHT: The vertical distance between the standing surface and the lowest point of the juncture of the curve of a buttock with the thigh (gluteal furrow).	76.1	81.7	87.3
61 HAND BREADTH: The breadth of the hand between the second and the fifth metacarpal-phalangeal joints.	8.5	9.0	9.4
62 HAND BREADTH ACROSS THUMB: The breadth of the hand, perpendicular to its long axis, at the level of the metacarpal-phalangeal joint of the thumb.	9.7	10.3	10.8
63 HAND CIRCUMFERENCE: The circumference of the hand around the second and fifth metacarpal-phalangeal joints.	20.7	21.7	22.6
64 HAND CIRCUMFERENCE INCLUDING THUMB: The circumference of the hand, perpendicular to its long axis, passing over the first metacarpal-phalangeal joint.	24.6	25.9	27.2
65 HAND LENGTH: The distance between the end of the forearm (stylion) and the tip of the middle finger (dactylion) parallel to the long axis of the hand.	18.3	19.2	20.1
66 HAND THICKNESS: The thickness of the hand between the palm and the top of the third knuckle of the hand (head of the third metacarpal).	2.7	2.8	2.9

TABLE 1 (cont'd)







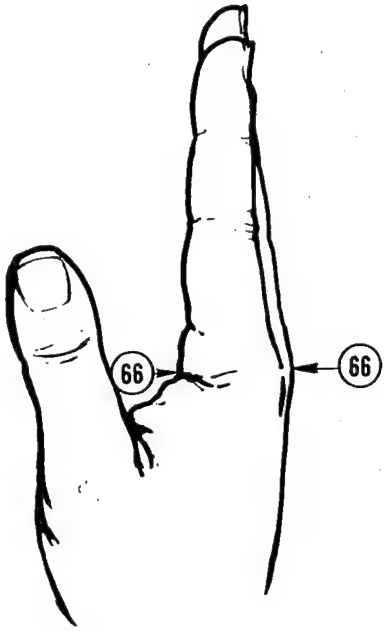


TABLE 1 (cont'd)

	Dimension Descriptions	DESIGN VALUES (cm)		
		SMALL	MID	LARGE
67	HEAD BREADTH: The maximum horizontal breadth of the head above the ears.	15.4	15.6	15.9
68	HEAD CIRCUMFERENCE: The maximum circumference of the head above the browridges and ears.	56.5	57.7	58.8
69	HEAD DIAGONAL FROM INION TO PRONASALE: The distance between the tip of the nose (pronasale) and the point inion on the back of the head.	21.5	22.0	22.5
70	HEAD DIAGONAL-MAXIMUM FROM MENTON TO OCCIPUT: The maximum distance between the tip of the chin (menton) and the back of the head (occiput).	25.0	25.7	26.3
71	HEAD LENGTH: The maximum distance from the mid-sagittal point between the browridges (glabella) to the back of the head	19.5	19.9	20.3
72	HEEL-ANKLE CIRCUMFERENCE: The circumference of the foot and ankle passing under the tip of the heel and over the anterior juncture of the foot with the ankle.	32.1	34.2	36.2
73	HIP BREADTH: The maximum horizontal breadth of the hips.	32.9	35.7	38.2
74	HIP BREADTH, SITTING: The maximum horizontal breadth of the hips of a seated subject.	34.8	38.3	41.5
75	HUMERAL BREADTH (Bone): The breadth of the humerus between its medial and lateral epicondyles with the tissue compressed.	6.8	7.1	7.5
*76	ILIOCRISTALE HEIGHT: The vertical distance from the standing surface to the top of the pelvis (ilium) in the midaxillary line.	100.0	107.3	114.5
77	INSTEP CIRCUMFERENCE: The vertical circumference of the arch of the foot.	24.3	25.9	27.4
78	INSTEP LENGTH: The horizontal distance between the back of the heel and the level of the maximum medial protrusion of the foot.	18.8	19.9	21.0
79	INTEROCULAR BREADTH: The horizontal distance between the inner corner of each eye (endocanthus).	3.3	3.3	3.4
80	INTERPUPILLARY BREADTH: The horizontal distance between the center of the pupil of each eye.	6.2	6.3	6.4
81	INTERSCYE: The horizontal surface distance across the back between the lowest points of the posterior axillary folds.	36.7	39.2	41.3

* See section on Body Size, page 6.

TABLE 1 (cont'd)

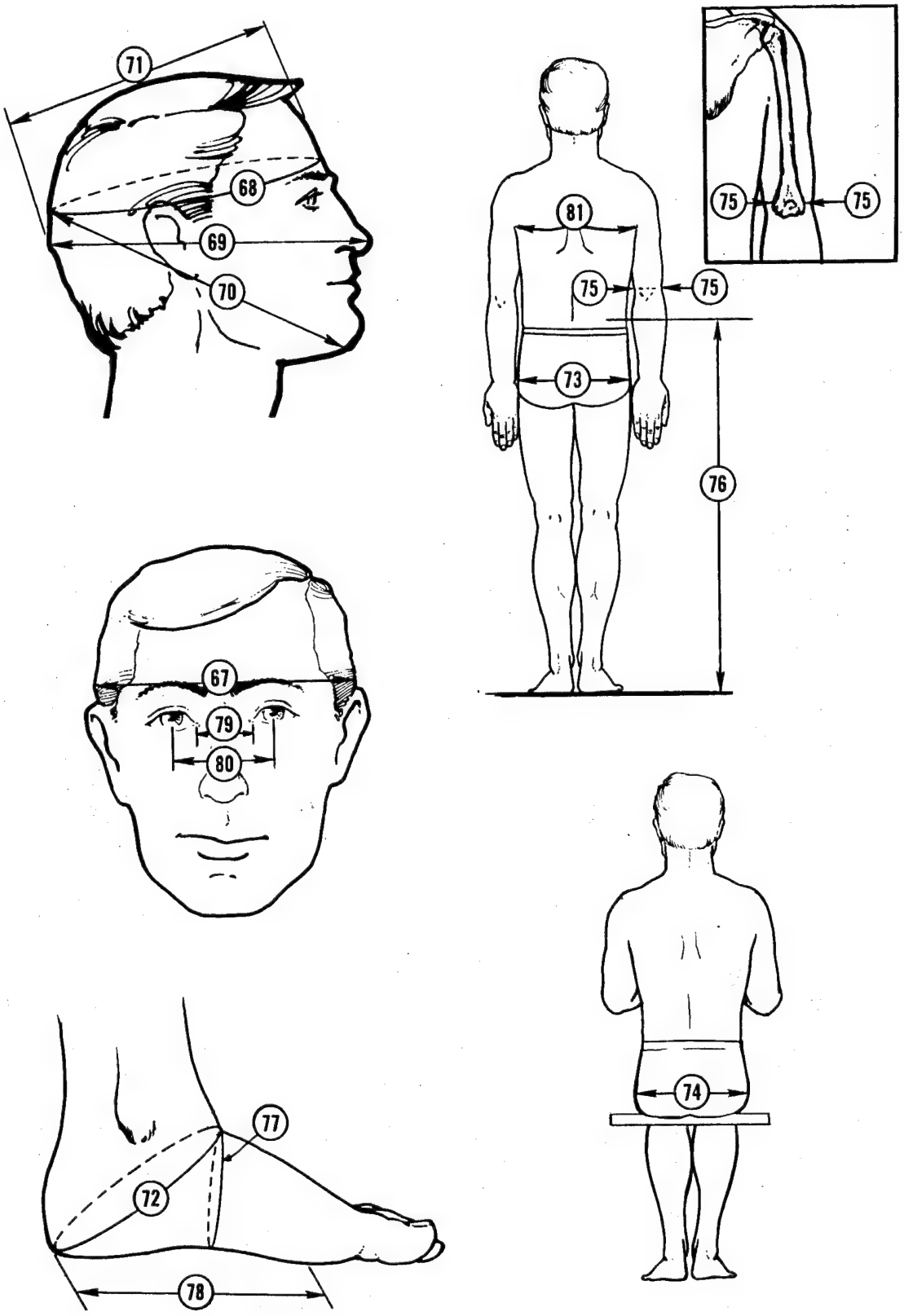
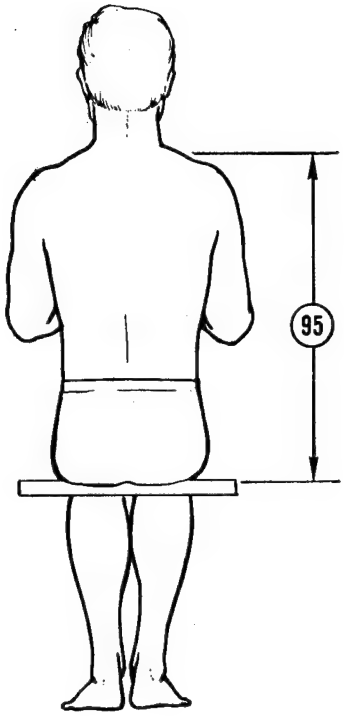


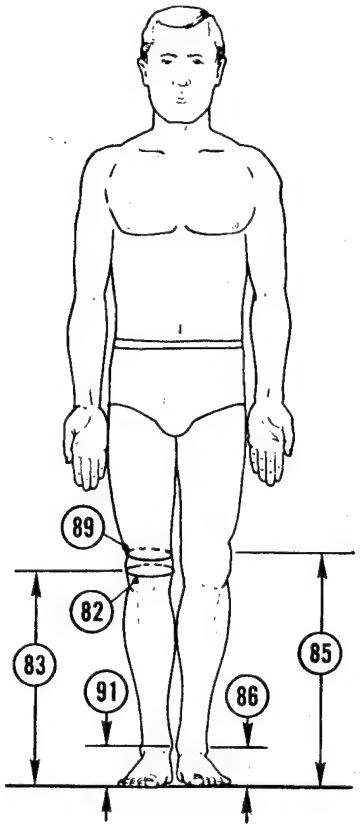
TABLE 1 (cont'd)

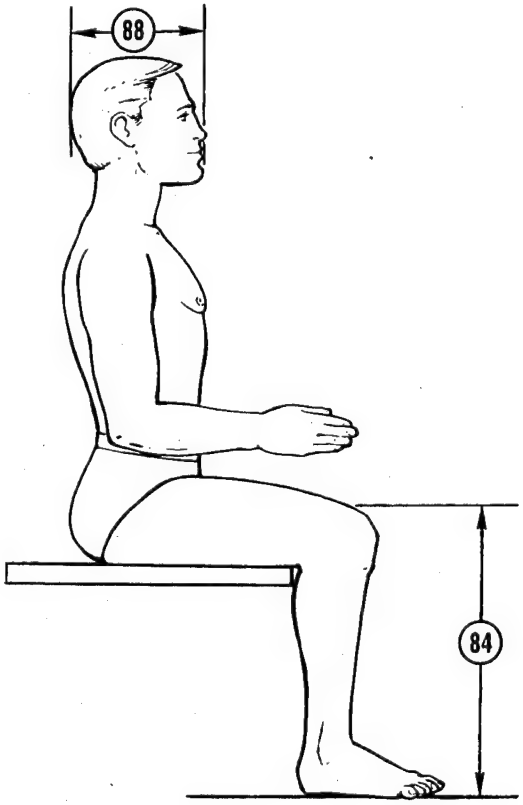
Dimension Descriptions	DESIGN VALUES (cm)		
	Small	Mid	Large
82 KNEE CIRCUMFERENCE: The horizontal circumference of the knee at the level of the middle of the kneecap (patella).	35.9	39.2	42.1
83 KNEE HEIGHT: The vertical distance between the standing surface and the level of the middle of the kneecap (patella).	46.4	50.0	53.6
84 KNEE HEIGHT, SITTING: The vertical distance between a footrest surface and the top of a knee of a seated subject. The knee is flexed 90 degrees.	52.3	56.2	60.0
*85 LATERAL FEMORAL EPICONDYLE HEIGHT: The vertical distance between the standing surface and the level of the maximum protrusion of the lateral femoral epicondyle.	47.6	51.0	54.3
86 LATERAL MALLEOLUS HEIGHT: The vertical distance between the standing surface and the lateral point of the ankle.	6.6	7.1	7.6
87 LIP LENGTH: The horizontal distance between the outer corners of the lips.	5.1	5.2	5.4
88 LIP PROTRUSION TO WALL: The horizontal distance between the most protruding point of the lips and the plane of the back of the head.	20.7	21.2	21.7
*89 LOWER THIGH CIRCUMFERENCE: The circumference of the thigh just above the kneecap (patella).	38.4	43.7	47.9
90 MAXIMUM FRONTAL (Forehead) BREADTH: The horizontal distance between the lateral ends of the browridges.	11.4	11.6	11.9
91 MEDIAL MALLEOLUS HEIGHT: The vertical distance between the standing surface and the medial point of the ankle.	8.1	8.6	9.1
92 MENTON-SELLION LENGTH (Face Length): The distance between the tip of the chin (menton) and the deepest point of the nasal root depression (sellion).	11.7	12.1	12.4
93 MENTON-SUBNASALE LENGTH: The distance between the tip of the chin (menton) and the base of the nose (subnasale).	6.7	6.9	7.1
94 MENTON TO TOP OF HEAD: The vertical distance between the tip of the chin (menton) and the plane of the top of the head	22.3	22.8	23.3
95 MIDSHOULDER HEIGHT, SITTING: The vertical distance between the sitting surface and the midpoint of the top of the shoulder (half the distance between the lateral base of the neck and acromion).	61.3	65.0	68.6

* See section on Body Size, page 6.

TABLE 1 (cont'd)







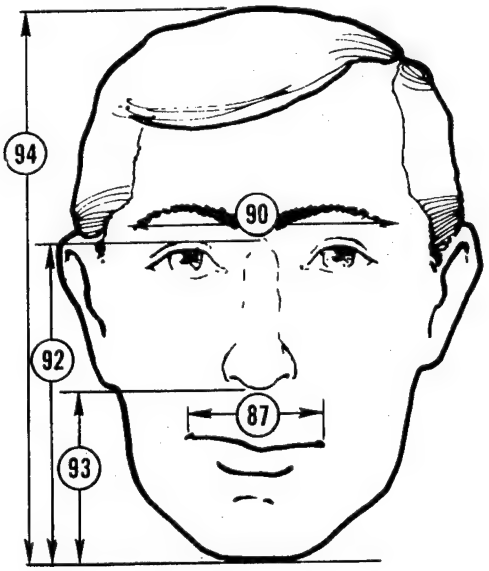


TABLE 1 (cont'd)

Dimension Descriptions	DESIGN VALUES (cm)		
	Small	Mid	Large
96 MINIMUM FRONTAL ARC: The surface distance between the points of greatest indentation of the temporal crests.	13.4	13.6	13.9
97 NASAL BREADTH: The maximum horizontal breadth of the nose.	3.5	3.6	3.6
*98 NASAL ROOT BREADTH: The horizontal breadth of the root of the nose.	1.5	1.8	2.1
99 NECK CIRCUMFERENCE: The maximum circumference of the neck, including the Adam's apple, perpendicular to its long axis.	36.5	38.7	40.6
100 NOSE LENGTH: The distance between the lowest point of the nasal septum (subnasale) and the deepest point of the nasal root depression (sellion).	5.0	5.1	5.3
*101 NOSE PROTRUSION: The distance between the tip of the nose (pronasale) and the lowest point of the nasal septum (subnasale).	2.0	2.4	2.8
*102 NUCHALE HEIGHT: The vertical distance in the midsagittal plane between the standing surface and the lowest palpable bony point of the back of the head (nuchale).	151.2	161.2	170.7
103 PALM LENGTH: The vertical distance between the distal end of the radius (stylion) and the crease at the base of the middle finger.	10.4	10.9	11.4
104 PHILTRUM LENGTH: The length of the groove between the upper lip and the base of the nose.	1.5	1.6	1.6
105 POPLITEAL HEIGHT: The vertical distance between a footrest surface and the lower lateral surface of the thigh, just behind the knee, when the subject is seated with the knee flexed 90 degrees.	41.2	44.0	46.7
106 PRONASALE TO TOP OF HEAD: The vertical distance between the tip of the nose (pronasale) and the plane of the top of the head.	14.5	14.8	15.0
107 PRONASALE TO WALL: The horizontal distance between the tip of the nose (pronasale) and the plane of the back of the head.	**	**	**
108 RADIALE-STYLION LENGTH: The distance, along the long axis of the forearm, between the proximal end of the radius (radiale) and the distal end of the radius (stylion)	25.3	27.1	28.8

* See section on Body Size, page 6.

** These values deleted due to inconsistancy with 121; the 121 values are deemed to be correct.

TABLE 1 (cont'd)

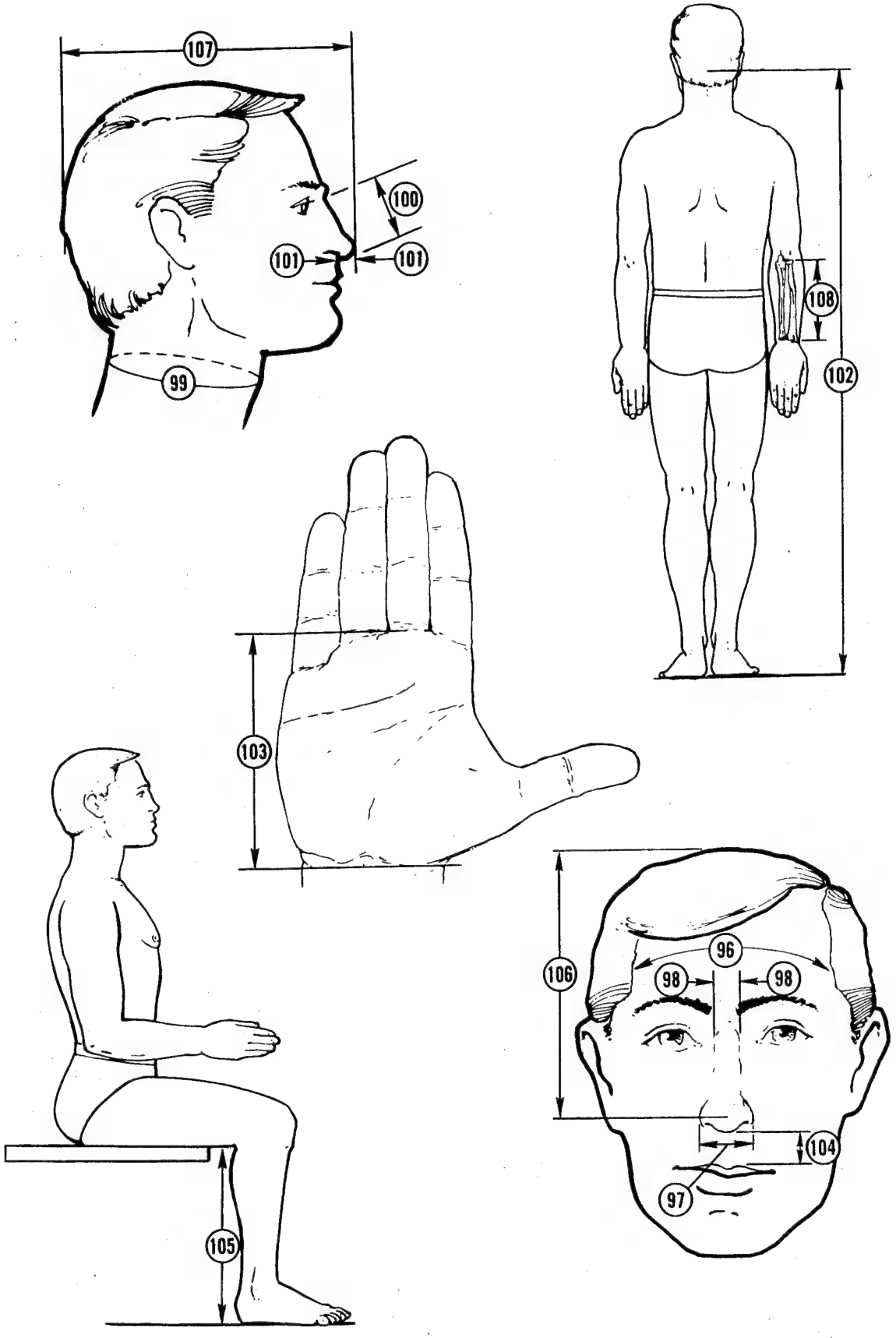
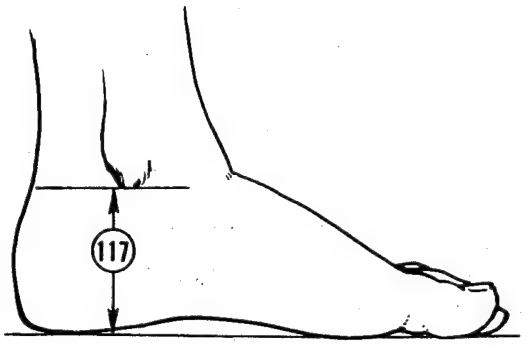


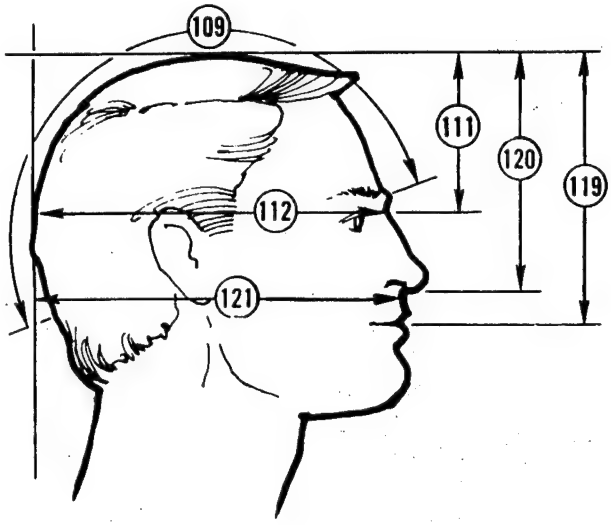
TABLE 1 (cont'd)

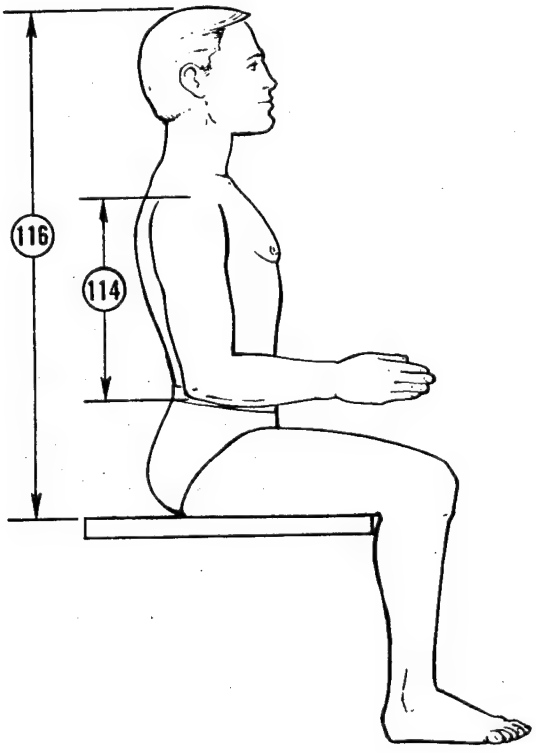
	Dimension Descriptions	DESIGN VALUES (cm)		
		Small	Mid	Large
109	SAGITTAL ARC: The surface distance over the top of the head from the point between the browridges (glabella) to the bony point on the back of the head (inion).	34.2	34.7	35.2
110	SCYE CIRCUMFERENCE: The vertical circumference passing over the shoulder and through the highest point of the axilla.	45.1	48.9	52.3
111	SELLION TO TOP OF HEAD: The vertical distance between the deepest point of the nasal root depression (sellion) and the plane of the top of the head.	10.5	10.8	11.0
112	SELLION TO WALL: The horizontal distance between the deepest point of the nasal root depression (sellion) and the plane of the back of the head.	19.8	20.2	20.6
113	SHOULDER CIRCUMFERENCE: The maximum horizontal circumference of the shoulders at the level of the deltoid muscles.	110.6	119.1	126.4
114	SHOULDER-ELBOW LENGTH: The distance, along the long axis of the upper arm, between the tip of the shoulder (acromion) and the bottom of the elbow (olecranon process) when the upper arm is hanging freely with the elbow flexed 90 degrees.	34.0	36.2	38.3
115	SHOULDER LENGTH: The surface distance between the lateral juncture of the base of the neck with the shoulder, and the tip of the shoulder (acromion).	15.8	16.7	17.6
116	SITTING HEIGHT: The vertical distance between the sitting surface and the top of the head.	89.3	93.7	98.0
*117	SPHYRION HEIGHT: The vertical distance between the standing surface and the distal end of the tibia (sphyrion).	6.5	7.0	7.5
118	STATURE: The vertical distance between the standing surface and the top of the head.	168.1	178.4	188.6
119	STOMION TO TOP OF HEAD: The vertical distance between the midpoint of closed lips and the plane of the top of the head.	18.0	18.4	18.8
120	SUBNASALE TO TOP OF HEAD: The vertical distance between the base of the nose (subnasale) and the plane of the top of the head.	15.8	16.1	16.5
121	SUBNASALE TO WALL: The horizontal distance between the lowest point of the nasal septum (subnasale) and the plane of the back of the head.	20.6	21.1	21.5

* See section on Body Size, page 6.

TABLE 1 (cont'd)







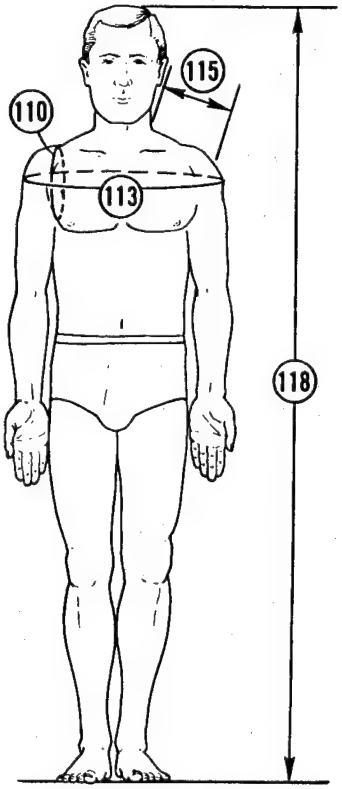
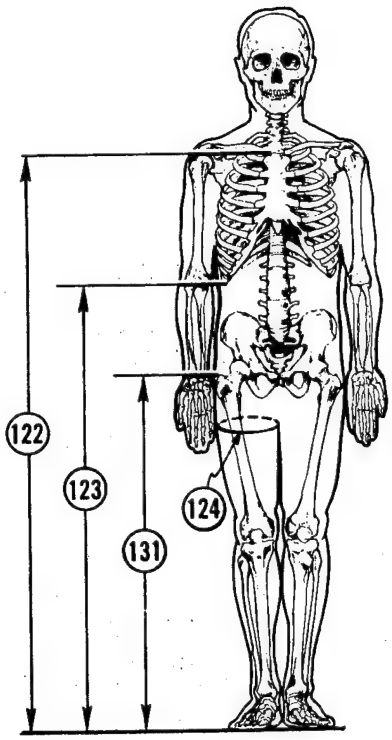


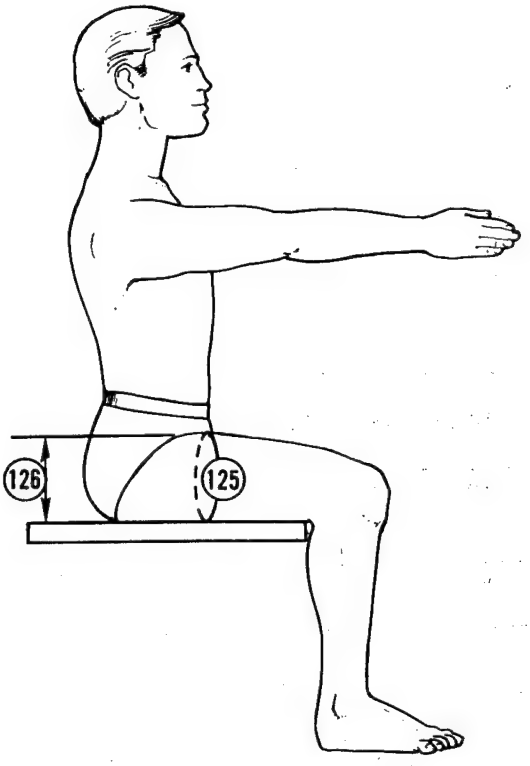
TABLE 1 (cont'd)

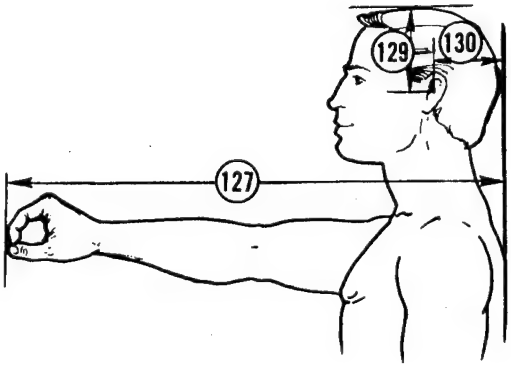
Dimension Descriptions	DESIGN VALUES (cm)		
	Small	Mid	Large
122 SUPRASTERNALE HEIGHT: The vertical distance between the standing surface and the point of deepest depression of the top of the breast-bone (suprasternale).	136.9	146.2	155.3
*123 TENTH RIB HEIGHT: The vertical distance between the standing surface and the level of the lowest point of the tenth rib.	105.1	112.5	119.8
124 THIGH CIRCUMFERENCE: The circumference of the thigh perpendicular to its long axis at the lowest point of the juncture of a buttock with the thigh.	53.7	59.9	65.2
125 THIGH CIRCUMFERENCE, SITTING: The vertical circumference of the thigh at its juncture with the groin of a seated subject.	52.7	58.9	64.2
126 THIGH CLEARANCE: The vertical distance between the sitting surface and the highest point on the thigh of a seated subject.	15.1	16.8	18.3
127 THUMB-TIP REACH: The horizontal distance between the plane of the back (a wall) and the tip of the thumb with an arm extended forward and the tip of the index finger touching the pad of the thumb. The palm is down.	76.0	80.8	85.5
128 THUMB-TIP REACH, EXTENDED: The horizontal distance between the plane of the back (a wall) and the tip of the thumb with an arm and a shoulder extended forward as far as possible while keeping the back of the other shoulder firmly against the wall. The tip of the index finger touches the pad of the thumb. The palm is down.	85.1	90.1	95.1
129 TRAGION TO TOP OF HEAD: The vertical distance between tragion and the plane of the top of the head.	13.2	13.5	13.7
130 TRAGION TO WALL: The horizontal distance between tragion and the plane of the back of the head.	10.2	10.4	10.5
131 TROCHANTERIC HEIGHT: The vertical distance between the standing surface and the top of the greater trochanter of the femur (trochanterion).	88.4	94.6	100.8

* See section on Body Size, page 6.

TABLE 1 (cont'd)







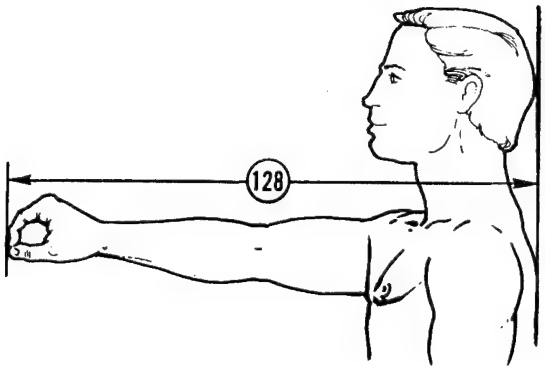
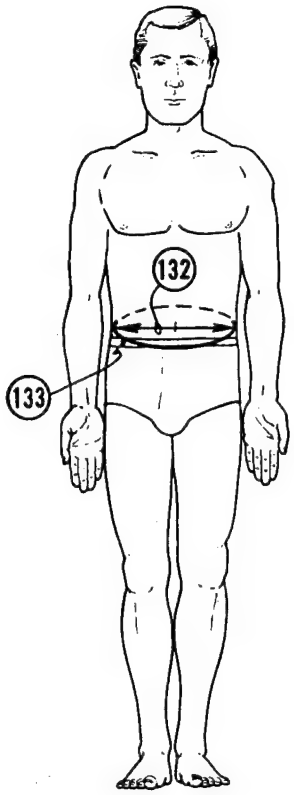


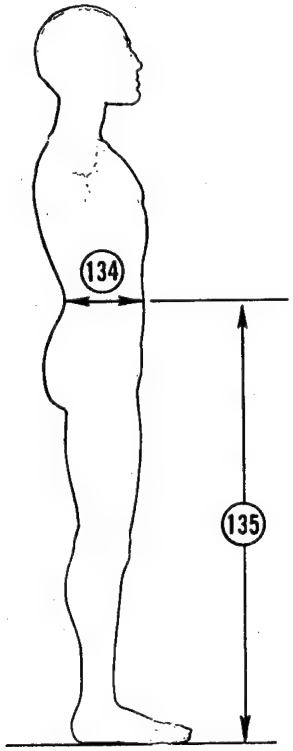
TABLE 1 (cont'd)

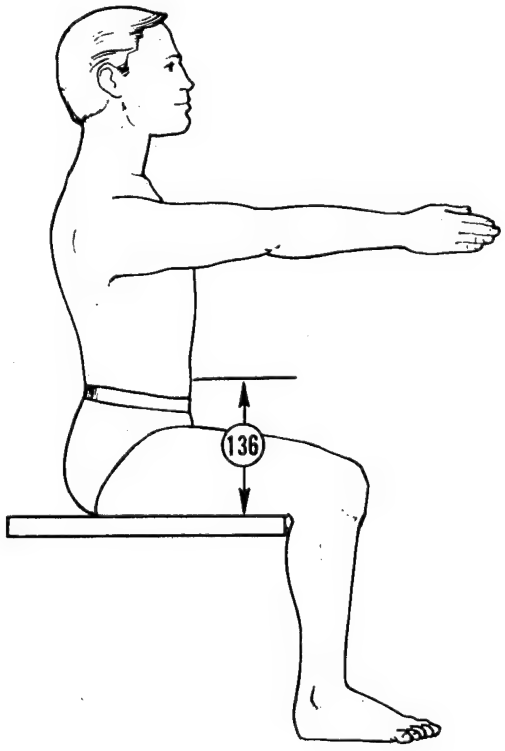
	Dimension Descriptions	DESIGN VALUES (cm)		
		Small	Mid	Large
132	WAIST BREADTH: The horizontal breadth of the torso at the level of the navel.	28.1	31.5	34.5
133	WAIST CIRCUMFERENCE: The horizontal circumference of the torso at the level of the navel.	79.0	89.4	98.2
134	WAIST DEPTH: The horizontal depth of the torso at the level of the navel.	20.2	22.8	24.9
135	WAIST HEIGHT: The vertical distance between the standing surface and the navel.	100.3	107.2	114.0
*136	WAIST HEIGHT, SITTING: The vertical distance between the seated surface and the navel.	21.5	22.4	23.4
137	WEIGHT: Weight of the subject to the nearest tenth of a pound.	139.5 lbs	179.7 lbs	215.4 lbs
*138	WRIST BREADTH (Bone): The maximum distance between the radial and ulnar styloid processes.	5.3	5.7	6.0
139	WRIST CIRCUMFERENCE: The circumference of the wrist perpendicular to the long axis of the forearm at the level of the distal tip of the radius (stylion).	16.7	17.7	18.7

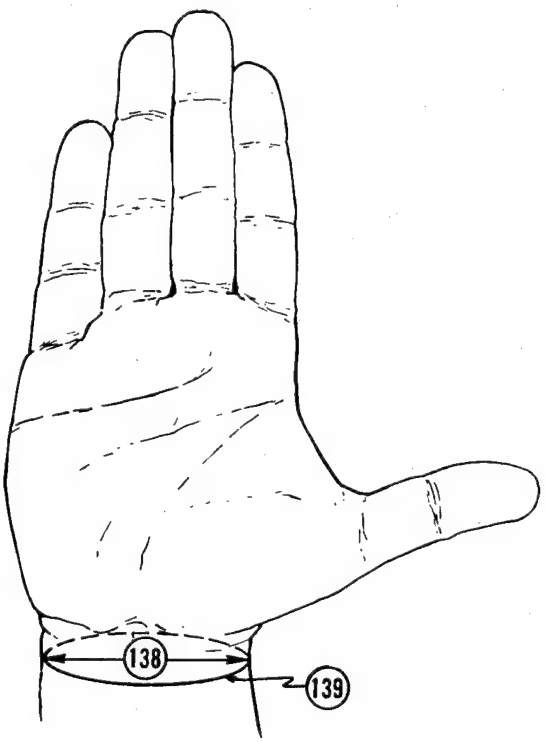
* See section on Body Size, page 6.

TABLE 1 (cont'd)









Body Segmentation

In order to describe its mass distribution properties, the body is segmented by planes as shown in Figure 2. These planes relate to the body in the erect standing position and are identified as described below:

1	HEAD PLANE:	A plane that passes through the right and left gonion and nuchale.
2	NECK PLANE:	A compound plane in which a horizontal plane through cervicale intersects anteriorly with a second plane. The second plane passes through the lower of the two clavicale landmarks, is perpendicular to the mid-sagittal plane, and makes a 45-degree angle with the horizontal plane.
3	THORAX PLANE:	A horizontal plane that passes through the 10th rib midspine landmark.
4	ABDOMINAL PLANE:	A horizontal plane passing through the higher of the two iliocristale landmarks.
5	HIP PLANE:	A plane perpendicular to the frontal plane passing through the center of the crotch and the midpoint between the anterior superior iliac spine landmark and trochanterion.
6	KNEE PLANE:	A horizontal plane passing through the lateral femoral epicondyle.
7	ANKLE PLANE:	A horizontal plane passing through the sphyrion landmark.
8	SHOULDER PLANE:	A plane passing through the acromion landmark and the anterior and posterior scye point marks of the axillary folds.
9	ELBOW PLANE:	A plane passing through the olecranon process and the medial and lateral humeral epicondyle landmarks.
10	WRIST PLANE:	A plane perpendicular to the long axis of the forearm passing through the radial stylion landmark.

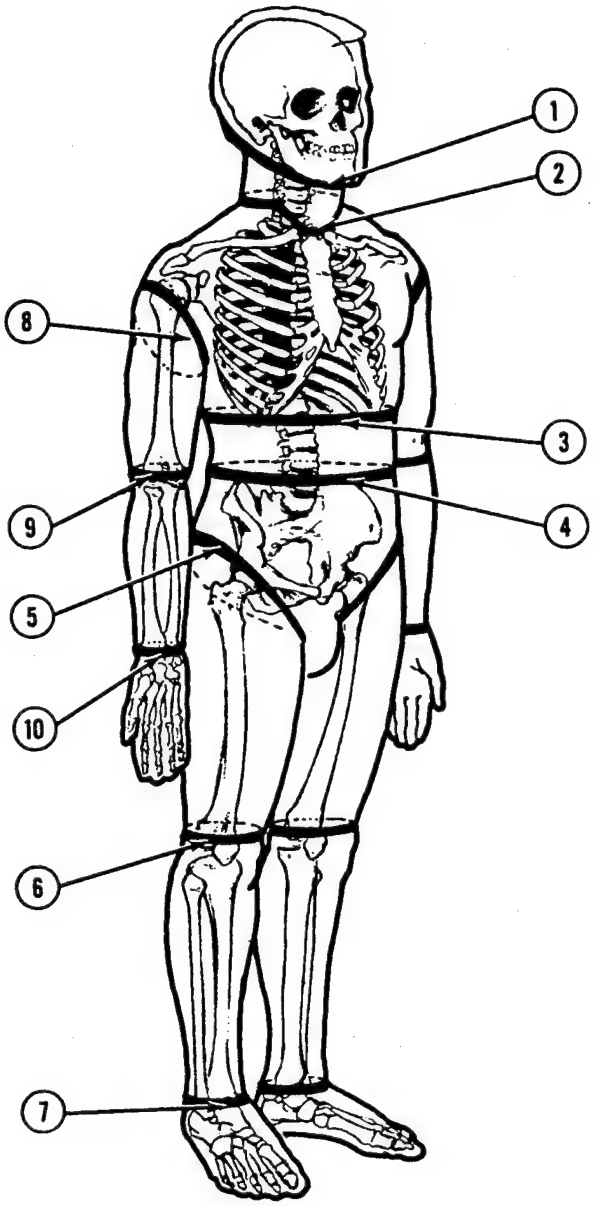


Figure 2. Planes of body segmentation.

Mass Distribution

The mass distribution data were calculated from regression equations reported in McConville et al. (1980). These data are based upon a stereophotometric assessment of volume. The assumption that the distribution of volume can be substituted for the distribution of mass is supported by the data reported in Young et al. (1983). The reader is referred there for more information.

The alignment of principal axes for each segment, the mass, and principal moments of inertia (calculated with respect to the segment center of mass) are presented in Table 2. A general assumption of body symmetry with respect to the midsagittal plane has been made so that properties of right and left segments are identical.

For purposes of specifying the segmental principal axes directions, a whole body reference axis system (r) is defined. This reference system is based on a standing surface in which the X_r axis points anteriorly, the Y_r axis to the left and the Z_r axis vertically upward.

The neck, thorax, and pelvis principal axes are rotated from this reference position, as shown in Table 2. The principal axes for the extremity segments (with the exception of the hand and foot) are such that the Z_p axis is aligned with the long axis of the bones and the X_p and Y_p axes are perpendicular to it with no preferred direction since the X_p and Y_p principal moments are equal. The orientation of the principal axes for the hand and foot are coincident with the reference axes.

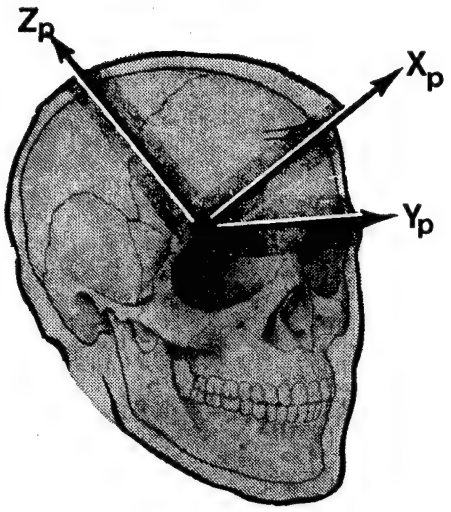
For the head, a local anatomically defined coordinate system (a) is used as the reference coordinate system. It is defined by the Y_a axis running from the right tragion to the left tragion, the X_a axis being the normal vector from the Y_a axis to the right infraorbitale, the Z_a axis being formed by the cross product of the X_a and Y_a axes vectors, and the origin being located on a line connecting the tragions (Y_a) at a point closest to sellion. The relative orientation of the head principal axes to the anatomical axes (a) is shown in Figure 3. For the head, the X_p axis is rotated 36° counterclockwise about the Y_a axis (see Table 2).

Segmental Masses

The segmental masses were determined from the relative proportions of segmental volumes obtained from regression equations developed by McConville et al. (1980), and total body masses of 63.3 kilograms for the Small sized man, 81.5 kilograms for the Mid-sized man and 97.7 kilograms for the Large sized man.

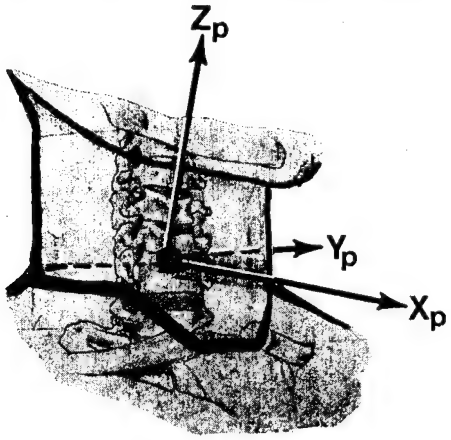
TABLE 2

MASS DISTRIBUTION OF THE BODY SEGMENTS
(mass in kilograms; moments of inertia in kilograms/cm^2;
X is anterior; positive rotation is clockwise)



HEAD				
	Segment Mass	Moments X	Y	Z
SMALL	4.0	193	219	144
MID-SIZE	4.2	206	235	153
LARGE	4.4	218	250	161

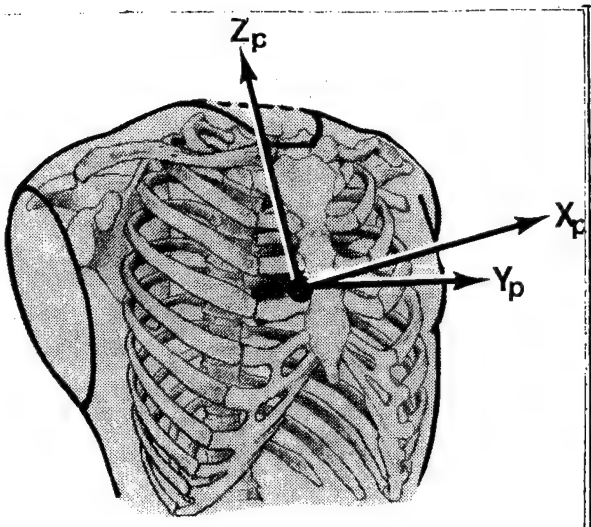
The principal axes are rotated $-36°$ about the Y_a axis.



NECK				
	Segment Mass	Moments X	Y	Z
SMALL	0.9	13	16	19
MID-SIZE	1.1	18	22	28
LARGE	1.2	23	27	35

The principal axes are rotated $+22.2°$ about the Y_r axis.

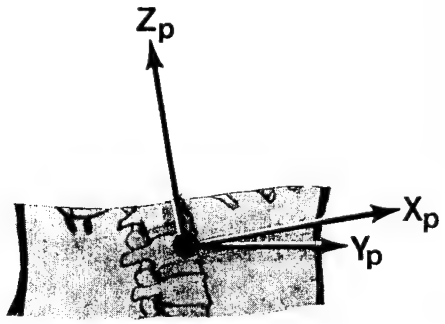
TABLE 2 (cont'd)



THORAX

	Segment Mass	Moments X	Y	Z
SMALL	18.6	3233	2347	1975
MID-SIZE	24.9	5224	3857	3284
LARGE	30.5	7002	5202	4432

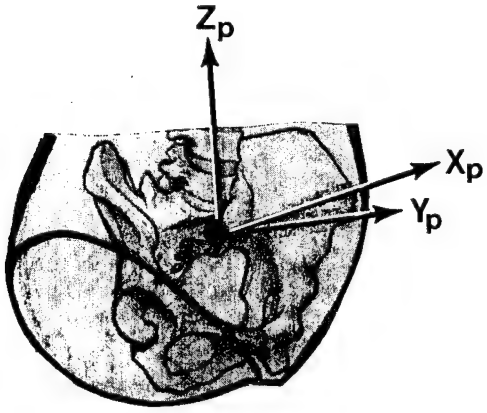
The principal axes are rotated $-12°$ about the Y_r axis.



ABDOMEN

	Segment Mass	Moments X	Y	Z
SMALL	1.9	108	58	160
MID-SIZE	2.4	175	99	266
LARGE	2.9	233	133	356

The principal axes are coincident with the reference axes.

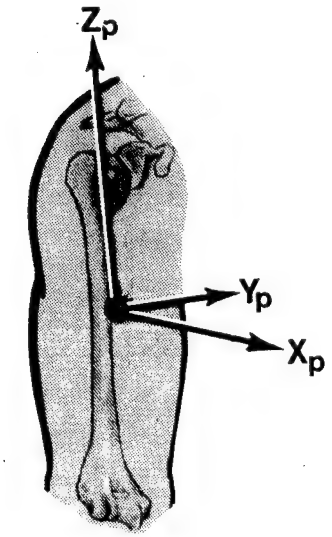


PELVIS

	Segment Mass	Moments X	Y	Z
SMALL	8.6	651	587	746
MID-SIZE	11.8	1116	1028	1298
LARGE	14.6	1519	1408	1773

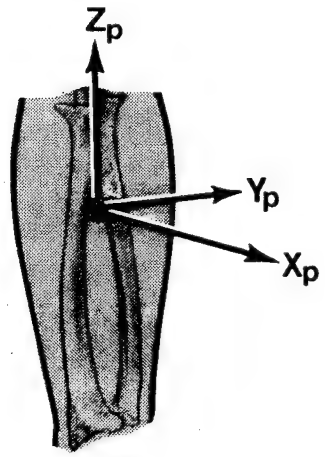
The principal axes are rotated $-24°$ about the Y_r axis.

TABLE 2 (cont'd)



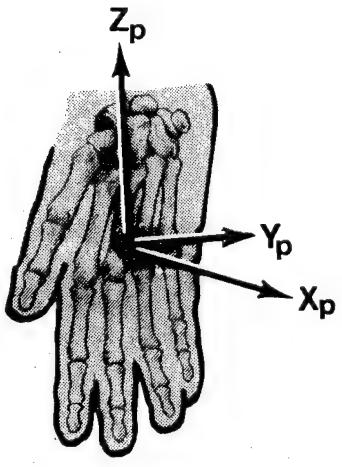
UPPER ARM				
	Segment Mass	Moments X	Y	Z
SMALL	1.5	85	85	17
MID-SIZE	2.0	141	141	29
LARGE	2.4	192	192	39

The Z_p axis is coincident with the Z_r axis and the X_p and Y_p axes are degenerate.



FOREARM				
	Segment Mass	Moments X	Y	Z
SMALL	1.1	61	61	9
MID-SIZE	1.4	90	90	14
LARGE	1.6	117	117	18

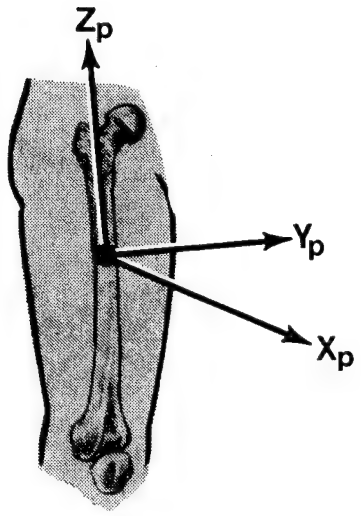
The Z_p axis is coincident with the Z_r axis and the X_p and Y_p axes are degenerate.



HAND				
	Segment Mass	Moments X	Y	Z
SMALL	0.5	10	8	3
MID-SIZE	0.5	13	11	4
LARGE	0.6	16	13	5

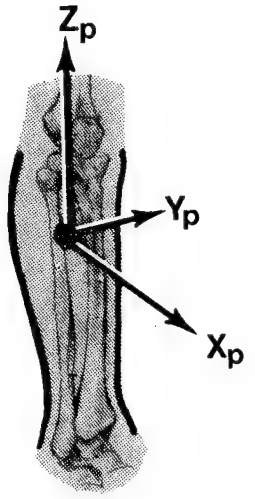
The principal axes are coincident with the reference axes with the hand aligned as shown in Figure 1.

TABLE 2 (cont'd)



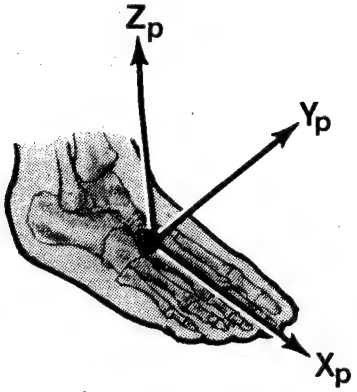
THIGH				
	Segment Mass	Moments X	Y	Z
SMALL	7.7	1093	1093	289
MID-SIZE	9.8	1652	1652	452
LARGE	11.8	2175	2175	595

The Z_p axis is coincident with the Z_r axis and the X_p and Y_p axes are degenerate.



CALF				
	Segment Mass	Moments X	Y	Z
SMALL	3.1	406	406	48
MID-SIZE	3.8	606	606	71
LARGE	4.5	798	798	92

The Z_p axis is coincident with the Z_r axis and the X_p and Y_p axes are degenerate.



FOOT				
	Segment Mass	Moments X	Y	Z
SMALL	0.8	6	31	33
MID-SIZE	1.0	8	44	46
LARGE	1.1	11	56	59

The principal axes are coincident with the reference axes with the feet aligned as shown in Figure 1.

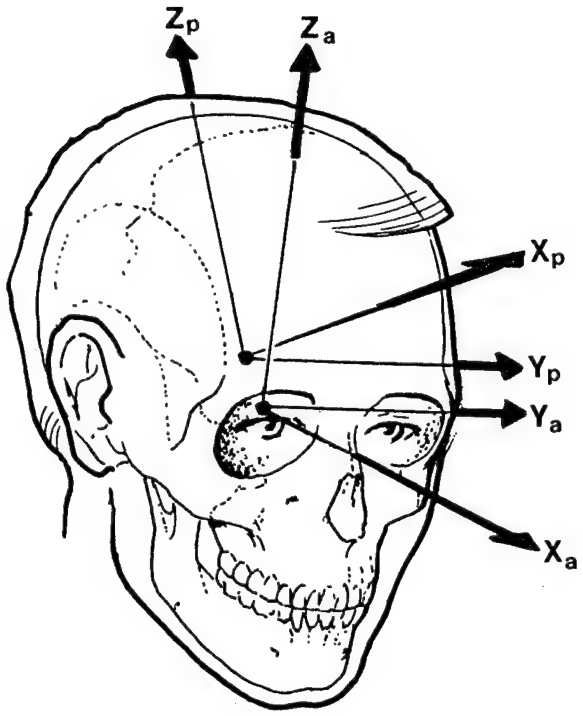


Figure 3. Principal axis orientation for the head relative to the anatomical axis system.

Body Linkage and Center of Mass (CM) Locations

Figures 4 through 9 illustrate the location of the centers of mass and joint centers for body segments for the Small, the Mid, and the Large sized male aviator. The centers of mass of the body segments with respect to their adjacent joint centers are assumed not to change from the standing to the seated position.

With the exception of the head, the centers of mass locations are based on the stereophotometric assessments of McConville et al. (1980). The location of the head center of mass is based on both the McConville data and that of Beier et al. (1979) and is similar to that derived by Robbins (1983).

The inserts in Figures 4, 6, and 8 show the estimated location of the trochanterion landmark with respect to the seated surface and a vertical plane tangent to the posterior surface of the buttock for an erect, seated posture. These data are based upon the data developed by Geoffrey (1961).

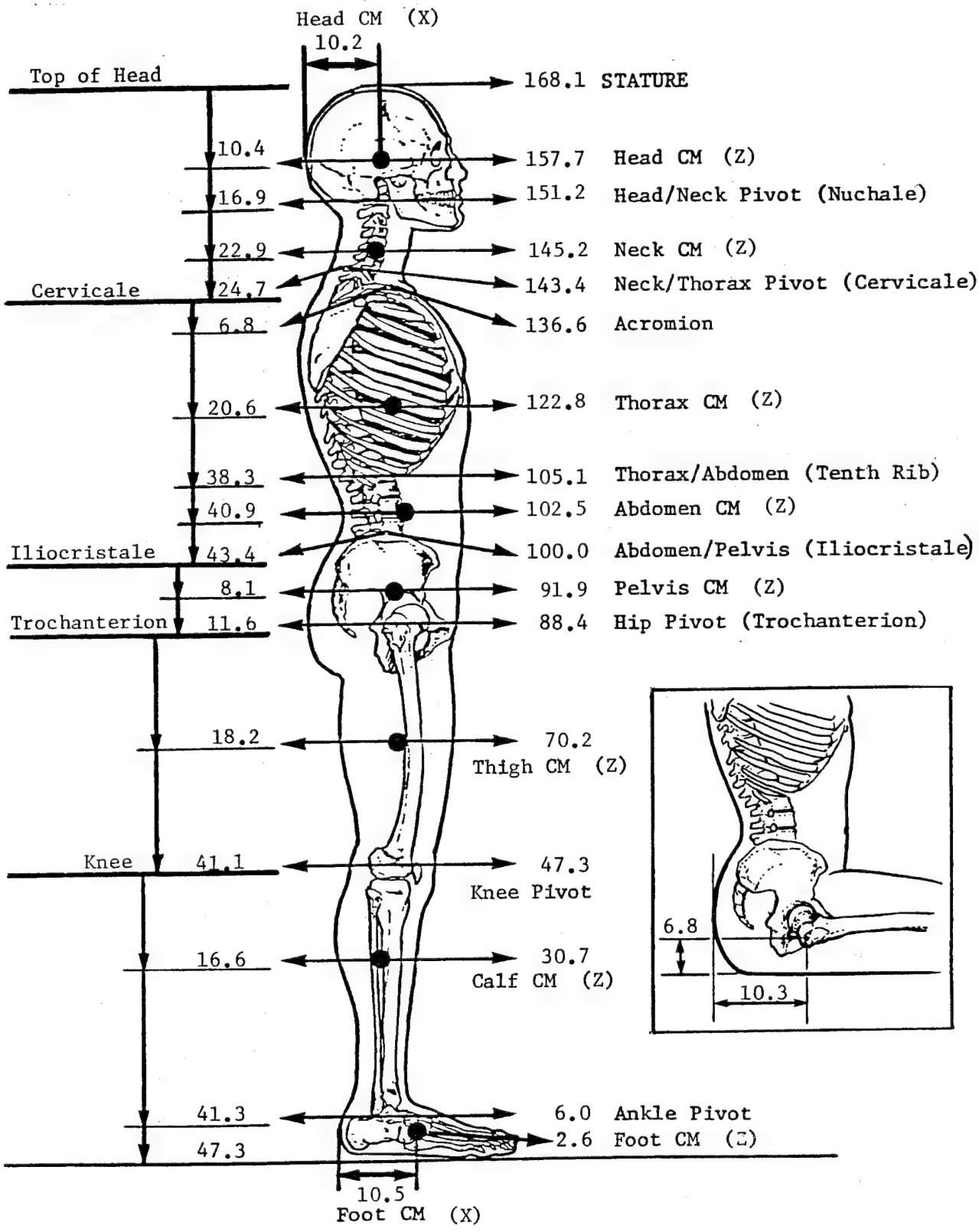


Figure 4. Body linkage and centers of mass (excludes arms) for the Small male aviator. Units are in centimeters.

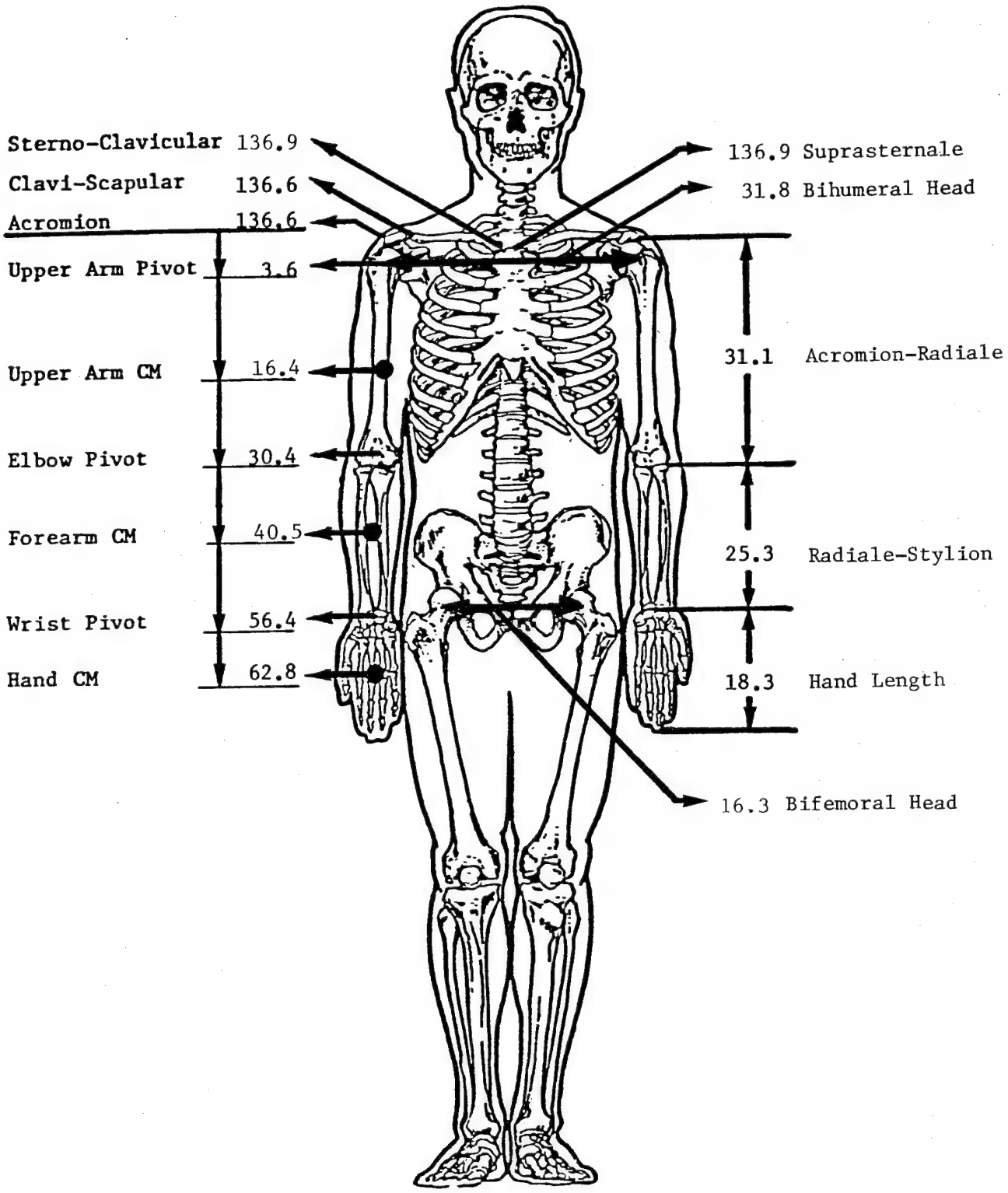


Figure 5. Centers of mass and linkage for the arms of the Small male aviator. Units are in centimeters.

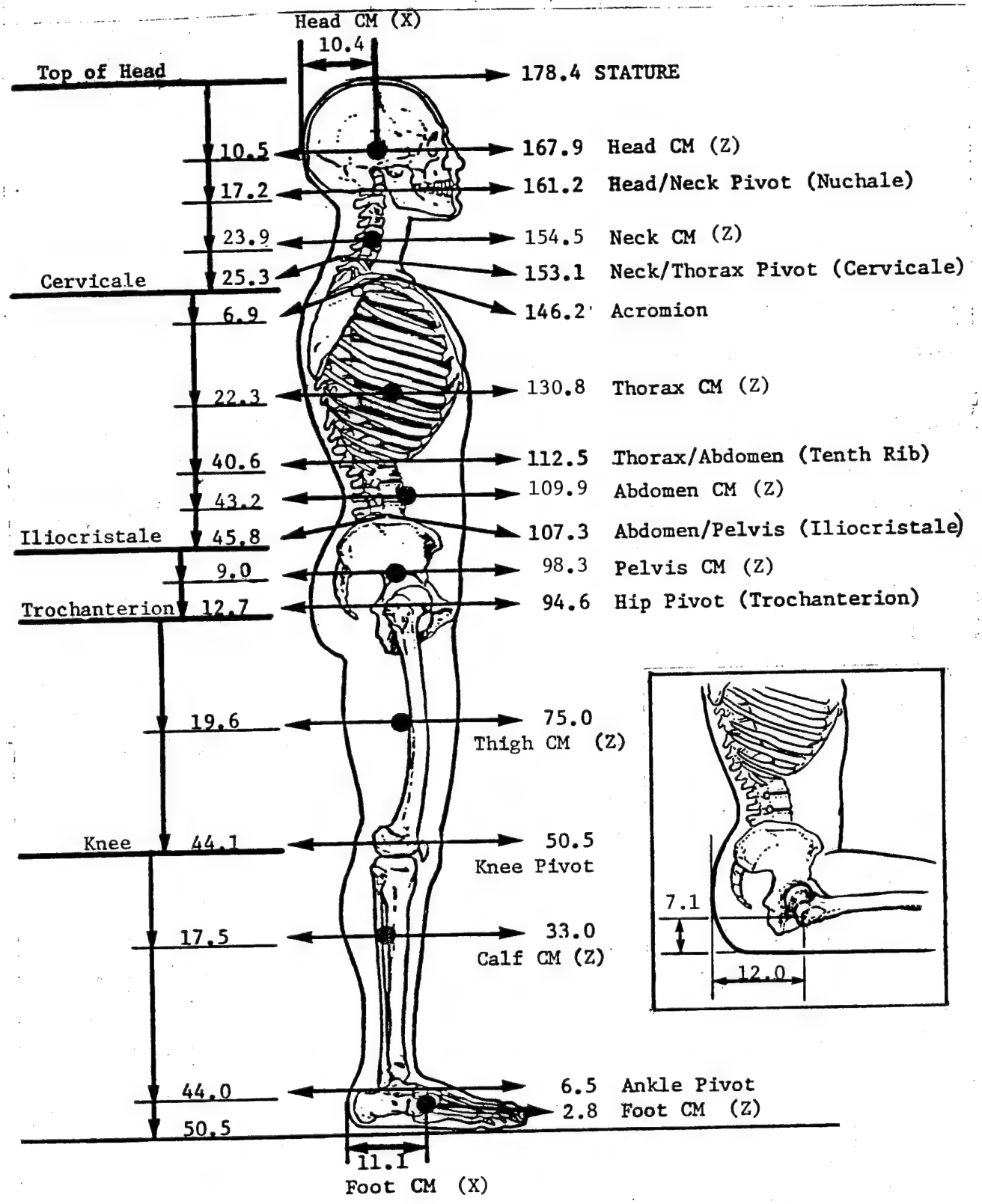


Figure 6. Body linkage and centers of mass (excludes arms) for the Mid-size male aviator. Units are in centimeters.

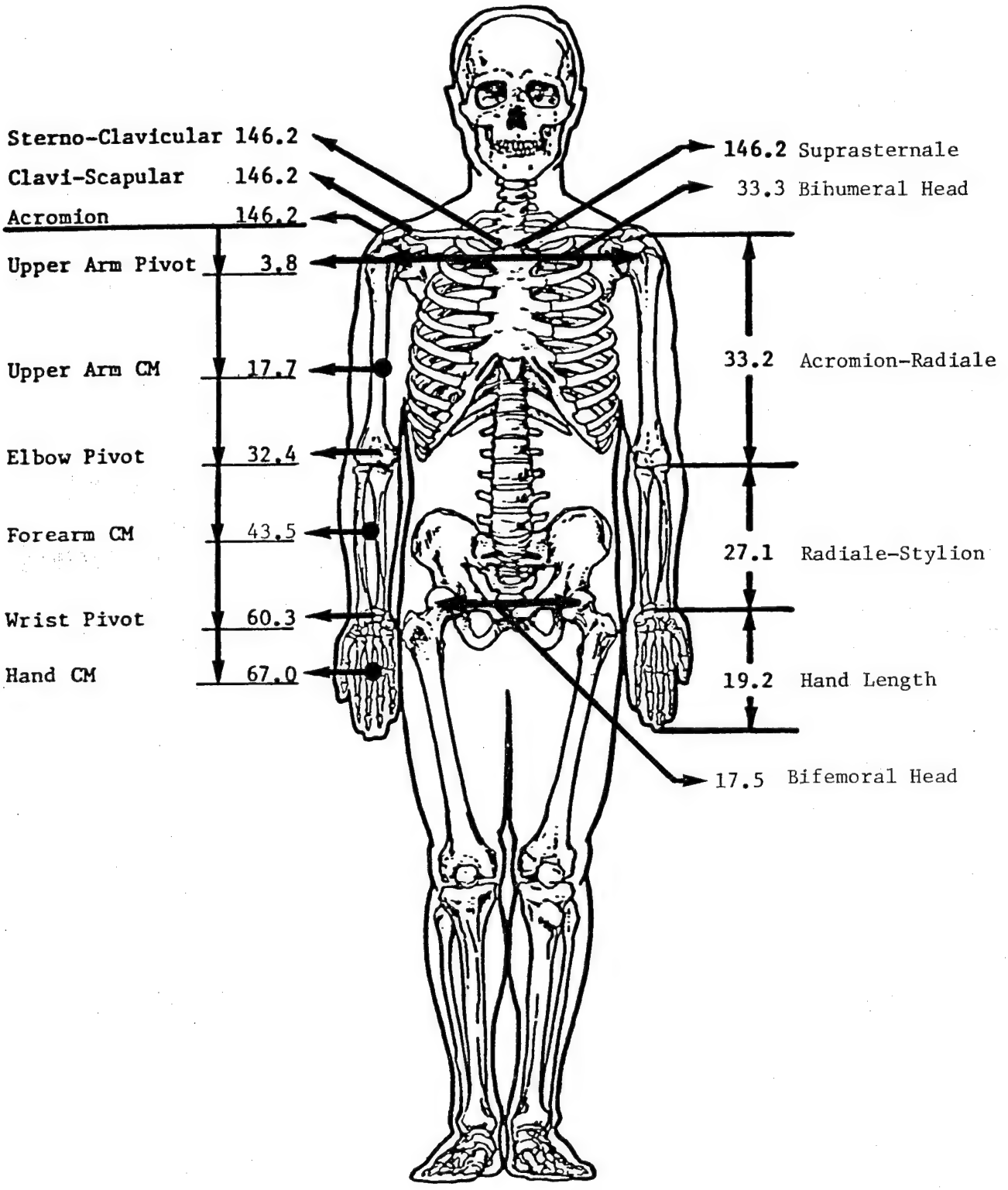


Figure 7. Centers of mass and linkage for the arms of the Mid-size male aviator. Units are in centimeters.

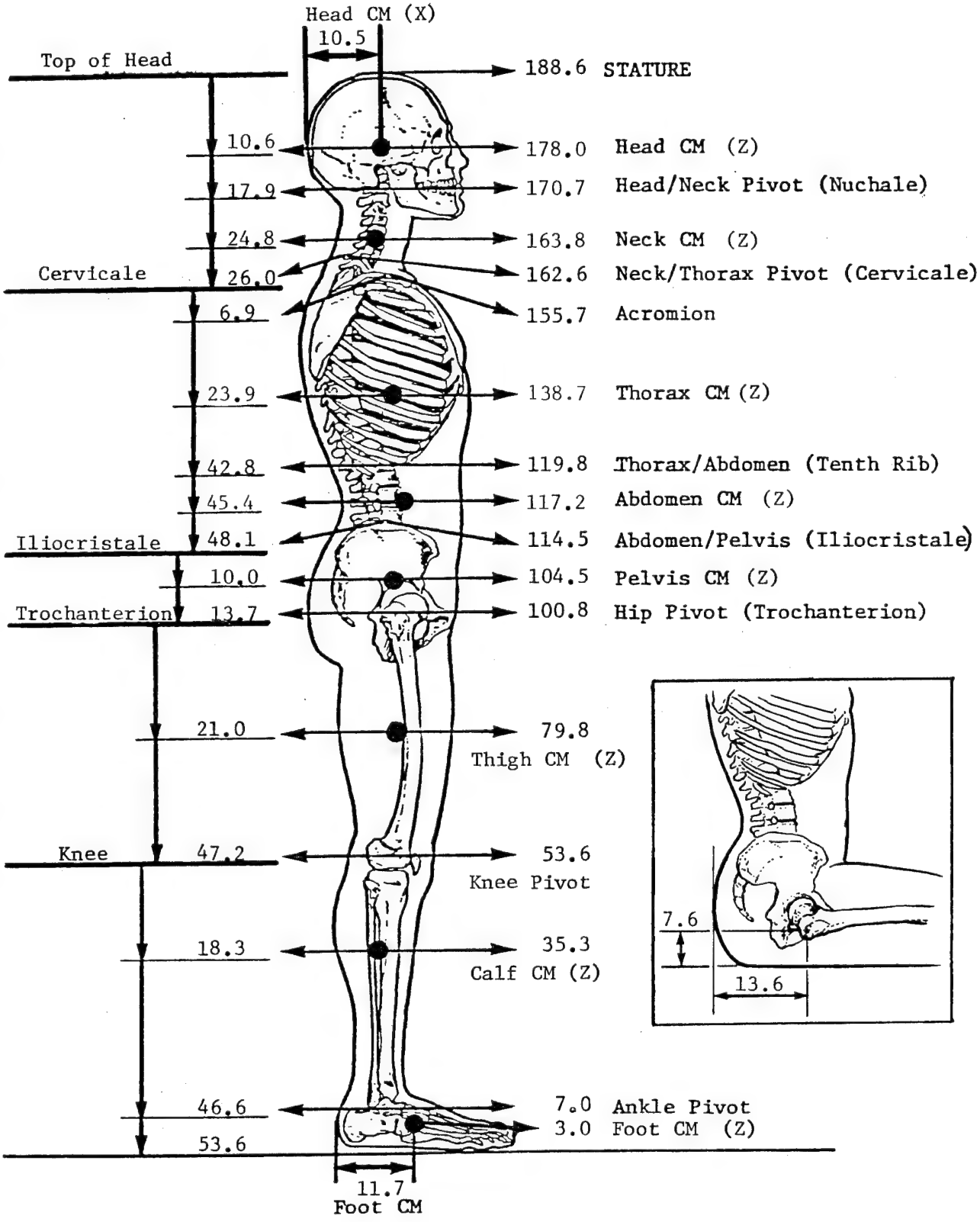


Figure 8. Body linkage and centers of mass (excludes arms) for the Large male aviator. Units are in centimeters.

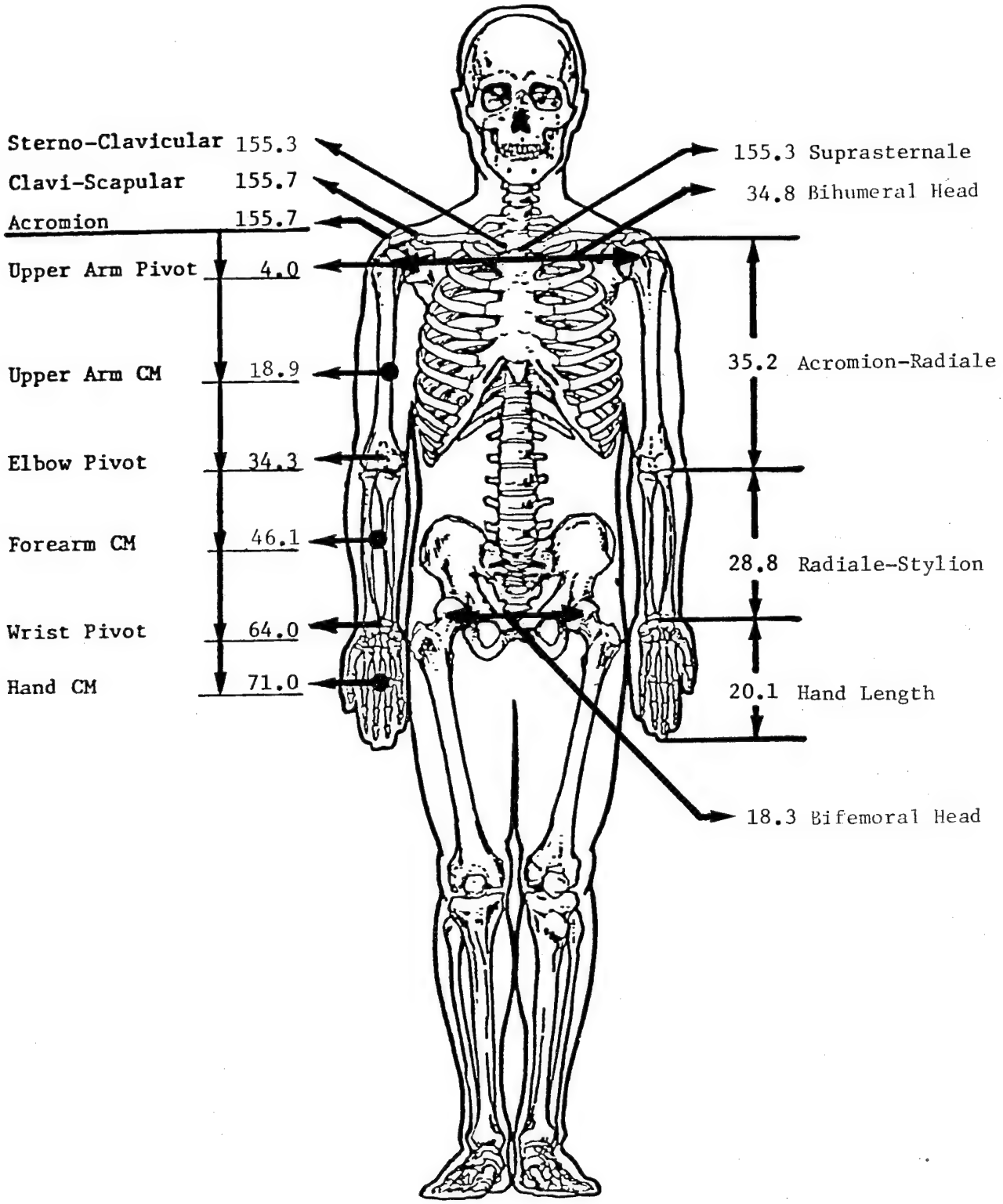


Figure 9. Centers of mass and linkage for the arms of the Large male aviator. Units are in centimeters.

DEFINITIONS

ABDOMEN:	As defined in this document, the abdomen is that segment of the torso bounded superiorly by a horizontal plane passing through the lowest point of the 10th rib and inferiorly by a horizontal plane passing through iliocristale.
ACROMION:	The lateral point on the bony tip of the shoulder.
ANTERIOR:	Pertaining to the front of the body; as opposed to posterior (see Figure 1).
ANTERIOR SUPERIOR ILIAC SPINE	The anterior end point of the crest of an ilium.
AXILLARY FOLDS:	The anterior and posterior folds formed by the juncture of the upper arms and the torso.
BI:	A prefix relating to each of two symmetrically paired points.
BICEPS (Brachii M.):	The large muscle on the anterior side of the upper arm.
BICRISTAL:	Pertaining to the crests of the ilia.
BIFEMORAL HEAD BREADTH:	The horizontal distance between the center of the head of the right and left femur. (Estimates derived from cadaveric material.)
BIHUMERAL HEAD BREADTH:	The horizontal distance between the center of the head of the right and left humerus. (Estimates derived from cadaveric material.)
CERVICALE:	The superior point on the spinous process of the 7th cervical vertebra.
CLAVICALE:	The superior point of the medial end of the clavicle.
CORONAL:	Pertaining to the crown of the head.
DACTYLION:	The tip of the middle finger.
DELTOID MUSCLE:	A large muscle passing over the top of the shoulder and inserting into the upper half of the humerus.
DISTAL:	The end of a body segment furthest from the torso; the opposite of proximal (see Figure 1).

ECTOCANTHUS: The point of the juncture of the eyelids at the lateral corner of an eye.

ENDOCANTHUS: The inner corner of an eye.

EPICONDYLES: Bony eminences at the distal ends of the humerus and femur.

FEMUR: The thigh bone.

FRANKFORT PLANE: The standard horizontal plane or orientation of the head. The plane passes through the right tragion and the lowest point of the right eye socket.

FRONTOTEMPORALE: The point of greatest indentation of the temporal crests.

GLABELLA: The anterior point in the midsagittal plane between the eyebrows.

GONION: The lateral point of the obtuse angle at the back of the lower jaw formed by the intersection of the vertical and horizontal portions of the jaw.

HUMERUS: The upper arm bone.

ILIOCRISTALE: A point in the midaxillary line on the crest of the ilium. The point is midway between the superior and lateral margins of the crest.

ILIUM (ILIA pl.): The upper one of three bones composing either half of the pelvis.

INFERIOR: Lower, nearer to the feet (see Figure 1).

INFRAORBITALE: Inferior point of the orbit of the eye.

INION: A protuberance of the occiput (the posterior bone of the skull) located in the center of the lower back of the head.

LANDMARK: A mark placed on the body or a body surface feature used to identify the origin, end-point, or level of a measurement.

LATERAL: Lying away from the midsagittal plane of the body; opposed to medial (see Figure 1).

LATERAL FEMORAL EPICONDYLE LANDMARK: The lateral point on the lateral femoral epicondyle.

LATERAL HUMERAL EPICONDYLE LANDMARK: The lateral point of the lateral humeral epicondyle.

LATERAL MALLEOLUS: The bony prominence at the distal end of the fibula.

LATERAL MALLEOLUS LANDMARK: The lateral point of the lateral malleolus.

MASTOID PROCESS: An inferior process of the temporal bone palpable just behind the ear.

MEDIAL: Lying near the midsagittal plane of the body; opposed to lateral.

MEDIAL HUMERAL EPICONDYLE LANDMARK: The medial point of the medial humeral epicondyle.

MEDIAL MALLEOLUS: The bony prominence at the distal end of the tibia.

MEDIAL MALLEOLUS LANDMARK: The medial point of the medial malleolus.

MENTON: The point of the tip of the chin in the midsagittal plane.

METACARPAL: One of five long bones of the palm of the hand. Numbered sequentially from I (thumb) through V (little finger).

METATARSAL: One of five long bones in the instep of the foot. Numbered sequentially from I (big toe) through V (little toe).

MIDAXILLARY LINE: A vertical line on the torso dividing it into front and back portions. The line originates at the center of the axilla.

MIDSAGITTAL PLANE: The vertical plane which divides the body into right and left halves.

NUCHALE: The lowest palpable bony point in the midsagittal plane of the back of the head.

OCCIPUT: Pertaining to the occiput, the bone making up the inferior part of the back of the skull.

OLECRANON PROCESS: The curved, hook-like head of the ulna that is the bony part of the back of the elbow. When the elbow is flexed 90 degrees, vertical measurements to the elbow are made to the bottom and horizontal measurements to the elbow are made to the back of the olecranon process.

PATELLA: The kneecap.

PHALANGES:	The bones in each of the fingers and toes.
PHILTRUM:	The vertical groove between the upper lip and the bottom of the nose (subnasale).
POPLITEAL:	Pertaining to the posterior surface of the knee.
POSTERIOR:	Pertaining to the back of the body; opposed to anterior.
PRONASALE:	The anterior point of the nose.
PROXIMAL:	The end of a body segment nearest the torso; opposed to distal.
RADIALE:	The lateral point of the head of the radius.
RADIUS:	One of the two bones of the forearm. It is on the thumb side of the upper extremity.
SELLION:	The lowest point in the midsagittal plane of the nasal root depression.
SCYE:	A tailoring term denoting the armhole of a garment. Scye points are the inferior points of the anterior and posterior axillary folds.
STYLION:	The distal point of the radius.
SPHYRION:	The distal point of the tibia.
SUBNASALE:	The point in the midsagittal plane at the juncture of the nasal septum with the philtrum.
SUPRASTERNALE:	The lowest point of the notch of the proximal end of the breastbone (manubrium).
TEMPORAL CREST:	A protruding ridge on the right and left sides of the frontal bone (the major anterior bone of the skull primarily underlying the forehead). It originates at the outside of a browridge and runs in a generally upwards and then backwards direction, where it becomes the inferior temporal line along the side of the skull.
TENTH RIB MIDSPINE LANDMARK:	A mark placed on the spine at the mean level of the inferior points of the right and left 10th ribs.
TIBIA:	The shinbone.

TRAGION: The superior point of the tragus (the cartilaginous flap in front of the ear).

TROCHANTERION: The highest point of the greater trochanter (a large, blunt bony process on the lateral side of the proximal end of the femur).

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